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SWS Contract Report 319

FINAL REPORT

NATIONWIDE URBAN RUNOFF PROJECT, CHAMPAIGN, ILLINOIS: ASSESSMENT OF THE IMPACT OF URBAN STORM RUNOFF ON AN AGRICULTURAL RECEIVING STREAM

by
G. Michael Bender
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prepared for

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
SPRINGFIELD, ILLINOIS
and
U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V-CHICAGO, ILLINOIS

June 1983

Contract No. 1-5-39600

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CONTENTS

BACKGROUND

In 1978 the U.S. Environmental Protection Agency (USEPA) concluded that available data concerning characteristics, impacts, and control of urban stormwater pollution were inadequate for needs of planning for future development and implementation of policy and programs. The National Urban Runoff Program (NURP), consisting of 28 projects nationwide, was a result of that decision. One of the 23 studies is being conducted by the Water Survey in Champaign.

Previous urban pollution studies, including those conducted by the Water Survey, has identified high concentrations of suspended solids, dissolved solids, metals, and nutrients as problems associated with urban runoff. Very little work has been done to date on the impact that this runoff has on receiving streams. The NURP program is concentrating on the evaluation of best management practices such as street sweeping and storm water detention. Although it has been shown that the runoff contains high concentrations of certain chemical constituents, the discharges to receiving streams are of short duration and may be of small volume when compared with runoff from the surrounding agricultural area.

Stormwater runoff is often combined with untreated sanitary overflows before reaching a receiving stream or discharges to the stream in close proximity to a sanitary plant discharge. For this reason, the small amount of biological data that exists upstream and downstream from such discharges often cannot be directly related to the stormwater runoff.

A recent study by the Natural History Survey indicates that biological studies can indeed differentiate between stormwater and sanitary discharge impacts. The sensitivity of the semi-quantitative analysis of benthic macroinvertebrate communities to identify urban impacts has been demonstrated. An "urban" impact from the city of Galesburg was documented in Cedar Creek in summer, 1980. Using the results of semi-quantitative benthic macroinvertebrate samples along the stream from well above the city, in the city but above the municipal wastewater outfall, and downstream through the recovery zone, cluster analysis identified an "urban" impact which was distinct from the impact of the wastewater outfall.

Because of the short duration of urban runoff, it is nearly impossible for investigators to reach and sample a stormwater outfall during an event, but the sediments in the streambed, which are repeatedly impacted by these events, serve as a record of the past. The finer grained sediments, in particular, have the capacity to attract and hold, by means of adsorption, absorption and ion exchange, a number of chemical substances. The structure and composition of benthic macroinvertebrate communities are sensitive to perturbations or alterations in the abiotic environment and, in general, their response to environmental stress is expressed as lower species diversity. Thus, benthic macroinvertebrates provide a valuable indicator of past and present water quality conditions.

STATEMENT OF PROBLEM

The impact of urban stormwater runoff on the biota of receiving streams is not known. Although the chemical quality of stormwater runoff is well documented and can be related to certain cultural and physical features of the watershed, data relating the impact on benthic communities to characteristics of the urban watershed do not exist. This is true despite the fact that most urban pollutants are associated with suspended solids that can accumulate in receiving streams.

RESEARCH PLANS

Up to 25 separate storm sewer outfalls in various cities in Illinois will be identified and the land use within their boundaries characterized. Those outfalls having watersheds with residential or commercial land uses and judged to be significant in relation to the size of the watershed of the receiving stream will be selected for further study. Industrial land use will be avoided due to the potential for toxic discharges that would be site specific. A maximum of ten outfalls meeting these criteria and other physical and biological constraints to be developed early in the study will be selected for detailed documentation. A program will be designed to obtain representative samples of stream water, bottom sediments, shoreline soils, and benthic macro invertebrates. Samples will be collected upstream and downstream from each outfall in late spring after flooding has dissipated and in the fall prior to killing frosts. Water samples will be analyzed for dissolved solids; soil (and sediment) samples will be visually classified and selected samples will be analyzed for grain size, clay mineral content, and chemical constituents associated with urban development; the macro invertebrate samples will be evaluated semi-quantitatively and the data will be statistically analyzed. Samples of the water and sediment will also be subjected to chemical analyses and benthic oxygen demand will be measured.

Physical documentation of the urban and receiving stream watersheds will be supplemented with channel cross sections upstream and downstream from the outfall.

The statistical techniques proposed to identify the impact of urban stormwater upon receiving streams have been tested in an earlier study. In a study of the impact upon receiving streams of high concentrations of total dissolved solids derived from coal mining, semi-quantitative benthic macroinvertebrate samples and extensive physical and chemical data were collected. Cluster analysis was used to define five physical-chemical clusters and a canonical analysis of discriminance validated the 5-cluster solution. Rotated correlations generated between the canonical discriminant functions and the discriminating variables identified the variables contributing to the differences observed among clusters. Site-assignment to a cluster appeared to be based primarily upon total dissolved solids, total sodium, pH, total suspended solids, total potassium, and fecal streptococcus. To identify which physical and chemical variables were the most reliable predictors of species diversity, stepwise regression procedures were performed using species diversity as a dependent variable.

SCHEDULE

Due to the seasonal requirements of the sampling in this project, the total length of the project is contingent on the starting date. A September 1 starting data would be ideal and was used on the attached schedule.

PRODUCTS

Products will include 2 semi-annual letter reports and a final report. The statistical analysis proposed will allow the investigators to determine cause and effect relationships between watershed variables and changes to the benthic communities. A unique data set will be generated and made available in machine-readable format. It is anticipated that this study will greatly enhance the opportunities for additional outside funding in this area.

ABSTRACT

From September 1981 through March 1983 an extension of the USEPA-NURP project in Champaign, Illinois was carried out by the Illinois State Water Survey for the Illinois Environmental Protection Agency. The purpose of the project extension was to evaluate the impact of urban runoff from Boneyard Creek on its receiving stream, the Saline Branch. Instruments for monitoring rainfall and runoff quantity and quality were installed at five sites, two on the urban stream and three on the receiving stream. Runoff data were collected for 31 storm events, a 22-day period of snowmelt, and 13 days of dry weather flows. A total of 1400 water samples were analyzed for 14800 constituent determinations, including solids, metals, and nutrients. Event mean concentrations and washoff loads of the sampled constituents were calculated for all events at each site. Additional data collection for the receiving stream included measurements of sediment oxygen demand, particle size distribution and constituent concentration of sediments, 24-hour diurnal dissolved oxygen, fish and macroinvertebrate populations, and habitat. Analysis of the runoff data indicated that the primary impact of urban runoff on the receiving stream is the 80-90 percent probability of elevation of stream concentrations of lead, copper, and iron above general use standards. Significant contributions of total suspended solids, phosphorus, ammonia-nitrogen, Kjeldahl nitrogen, and COD are also made to the receiving stream by the urban area. The metals which exceed standards are strongly associated with suspended solids, and the excursions above standards are of short duration. Effluent from the sewage treatment plant in the community has greater influence than urban runoff does on levels of phosphorus and ammonia-nitrogen in the receiving stream. The major long-term impacts of urban runoff on the receiving stream may actually be related more to physical effects of surging runoff flows flushing the stream and chemical effects of urban solids settling out and accumulating in the stream than to the temporary elevations of stream concentrations of urban pollutants.

EXECUTIVE SUMMARY

The Nationwide Urban Runoff Program was designed by the United States Environmental Protection Agency to investigate three aspects of urban storm runoff across the country: type and extent of urban runoff problems, impacts of urban runoff on receiving waters, and effectiveness of recommended control practices. One of the 28 projects in the program was awarded to the Illinois Environmental Protection Agency (IEPA), which contracted with the Illinois State Water Survey (ISWS) to perform an evaluation of the effectiveness of municipal street sweeping in controlling urban runoff quality. After data collection for that study was completed in August 1981, an extension of the project was granted for the purpose of assessing the impact of urban storm runoff on a receiving stream. Data collection in the project extension ran from October 1981 through September 1982, and the report was completed in May 1983.

Champaign-Urbana was the study area for the project extension. Five sites were instrumented for rainfall and streamflow quantity and quality monitoring. Two of the sites were located on Boneyard Creek, an urban stream which drains about 5.7 square miles of separately sewered urban area, including the central business districts of both Champaign and Urbana. The remaining three sites were located on the Saline Branch of the Vermilion River, an agricultural drainage ditch which receives the flow from the Boneyard within Urbana city limits. One of the three was placed upstream from any contribution from Champaign-Urbana, at a point where the drainage area of the stream is about 51 square miles of agricultural property, mostly tilled fields planted in row crops. Another was placed at a point 0.3 mile downstream from the confluence of the streams and 0.2 mile

upstream from the outfall of the Urbana-Champaign Sanitary District's northeast sewage treatment plant. The last site was located at a point 3.8 miles downstream from the treatment plant outfall, defining the boundary of the study area. Water level sensors and automatic flow samplers were placed at all five sites. Rating curves were supplied by the U.S. Geological Survey for two sites and determined by ISWS for the other three sites. Three rain gages and one wet-dry fallout sampler were also used in the equipment network. A computer-controlled telemetry system developed for the street sweeping evaluation study was revised and installed for collection, storage, and management of runoff event data. During storms, rainfall and flow data from the sites were recorded at one-minute intervals. Discrete samples for water quality analyses were ordered throughout the events at intervals which varied by site. Laboratory determinations of concentrations of a broad list of constituents, including solids, metals, and nutrients, were made on the runoff and rainfall samples. Altogether, 31 events were monitored and sampled during the data collection period. A 22-day period of snowmelt runoff in February and early March was also monitored continuously and sampled occasionally to permit calculation of the constituent loads in snowmelt.

Besides runoff event monitoring, there were several other sampling efforts in the data collection program. Dry weather flow samples were gathered for analysis of background constituent levels from 11 to 13 times at each site. Sediment oxygen demand tests were run at 14 points on the Saline. Sediment samples were collected at the upstream and downstream sites on the Saline for determination of particle size distribution of the entire sample and constituent concentration in the fines. Along with the development of rating curves for three sites, the performance of the automatic samplers was tested by comparing results of analysis of automatic and depth-integrated manual samples taken simultaneously at the site during wet and dry weather.

IEPA also contributed to the background data on the receiving stream. A 24-hour test to document diurnal fluctuation of dissolved oxygen was conducted at four sites in August 1982. Inventories of fish and macroinvertebrate populations at all five sites were carried out at different times in the study period. Habitat assessments were made at each site on the Saline. These efforts related specifically to evaluation of the biological condition of the receiving stream.

For each site, event mean concentrations and washoff loads of all constituents sampled were calculated for all events with reliable flow and water quality data. For selected constituents, individual plots of EMCs or loads at one site against those at another site were produced, featuring all events for which there were data for both sites. The sets of EMCs and loads of all constituents for all events at each site were also fitted to log-normal distributions, which were plotted with 90 percent confidence bands. The plots and calculated distributions of EMCs at each site were used to determine and compare characteristic responses of the streams to storm activity. Comparisons were also made of EMC results to general use water quality standards for lead, copper, iron, ammonia- nitrogen, and phosphorus, to determine the probability of exceedance of standards at any site due to storm runoff or other pollutant inputs. The plots and calculated distributions of the loads were used to determine the fates of individual constituents in the streams within the study area and to identify effects of unmonitored sources on constituent balances. The EMC and load data for the two urban sites were considered separately and collectively using stepwise multiple regression techniques to develop predictive expressions for EMCs and loads of selected constituents. Independent variables in the regression included area, total rainfall, rainfall duration, five-minute maximum rainfall, days since last rain, mean flow, and peak flow. Similar expressions were developed for the receiving stream sites based on the data set for each site.

The principal conclusions of the study were the following:

1. The primary water quality impact of urban runoff from Boneyard Creek on the Saline Branch receiving stream is the elevation of stream concentrations of lead, copper, and iron to levels 5-10 times background concentrations and well above water quality standards. For these constituents the probability range is 85-100 percent that event mean concentrations for an event will exceed standards in the Saline just downstream from the Boneyard. For total suspended solids, phosphorus, Kjeldahl nitrogen, and chemical oxygen demand, median EMCs in the Saline due to urban runoff range from 4 to 16 times routine background levels.

2. The elevated concentrations of the above-named constituents in the Saline have short durations, generally no more than two to three hours beyond the end of a storm event. Also, previous work has shown 30 percent of the TKN, 60 percent of the phosphorus, 70 percent of the copper, and virtually 100 percent of the lead and iron are associated with suspended solids.

3. The effluent from the sewage treatment plant has greater influence on receiving stream levels of phosphorus and NH3-N than has the urban stream, in storms as well as in dry weather. About 91 percent of the load of NH3-N to the Saline during the year of monitoring was attributable to the treatment plant effluent.

4. The TSS load carried by the Saline during the 22-day period of snowmelt runoff monitoring constituted 64 percent of the estimated total TSS load carried by the stream for the entire year of data collection.

5. The urban area constituted only 14 percent of the total study area but produced 28 percent of the annual load of TSS and 95 percent of the annual load of lead.

6. The results of limited sediment sampling showed increased constituent concentrations in fine particles in the downstream direction. Two to fivefold increases were seen for phosphorus, TKN, COD, zinc, and chromium, while tenfold or greater increases were observed for lead, copper, and mercury.

7. Although results of constituent loads analysis and sediment sampling indicate possible deposition of urban solids between sites 4 and 5, most of the urban solids are flushed through the system and out of the study area. The short residence time of urban runoff in the study area prevents assimilation of soluble pollutants and assures that they, too, pass through the system.

8. The characterization of urban runoff indicates that rainfall parameters such as total volume, average intensity, and maximum five-minute intensity have greatest influence on EMCs and loads of constituents in runoff. The length of dry period preceding a storm has no apparent influence on EMCs or loads.

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) initiated the Nationwide Urban Runoff Program (NURP) in 1978. The principal intent was to provide to the Congress information on which to base decisions regarding the need for control of urban storm runoff quality. At 28 locations across the country, projects were conducted in which data collection and interpretation were undertaken to address at least one of three objectives: 1) characterization of problems, including types and loads of pollutants; 2) assessment of impacts on receiving waters; and 3) evaluation of recommended best management practices.

One of the NURP projects was awarded to the Illinois Environmental Protection Agency (IEPA), which had proposed a study of the effectiveness of municipal street sweeping as a best management practice for urban runoff quality control. The study was carried out in Champaign, Illinois for IEPA by the Illinois State Water Survey (ISWS) during the years 1979-82. The conclusion was that mechanical street sweeping at conventional frequencies was not effective in reducing urban runoff pollutant loads. Appendix II contains data from the study not included in previous reports.

As the data collection phase of the street sweeping evaluation was drawing to a close in August 1981, IEPA proposed to USEPA that a one-year extension of the project be granted. The purpose of the extension was to assess the impact of urban runoff from the Champaign-Urbana area on its receiving stream. IEPA proposed to monitor flow and quality in Boneyard Creek, an urban stream, and Saline Branch, an agricultural drainage ditch into which Boneyard Creek flows. After USEPA approved the extension proposal, IEPA contracted with ISWS to perform the study, which was started in September 1981 and completed in March 1983. The work accomplished during the extension is the subject of this report.

OBJECTIVE

There were two objectives to be accomplished during this project. The first was to characterize urban storm runoff from Champaign-Urbana by intensively monitoring rainfall and runoff quantity and quality at two points on Boneyard Creek for every possible storm during the study period. Modeling and statistical techniques were to be used to develop expressions of runoff responses to the observed rainfall. These expressions would be the basis for extrapolations of the responses of this area to unmonitored areas.

The second objective was to determine the fate of pollutants carried by Boneyard Creek to its receiving stream, the Saline Branch, by monitoring flow and quality in the Saline for the same events. By sampling the Saline at points upstream and downstream from the Boneyard inflow, the effects of the loads of urban pollutants on the receiving stream could be determined. Knowledge of the fate of urban pollutants would be used in conjunction with results of additional evaluations of conditions in the Saline to determine whether urban runoff exerts a harmful impact on the receiving stream.

ACKNOWLEDGMENTS

This work was accomplished as part of the regular work of the Illinois State Water Survey under the administrative guidance of Stanley A.

Changnon, Jr., Chief. The work was performed under the administrative supervision of Michael L. Terstriep, Head of Surface Water Section, who was also Principal Investigator.

The following Water Survey employees worked full-time or part-time directly on project tasks of sample collection and handling and data reduction, analysis, and interpretation: Mike Sybeldon, Mark Wisthuff, and Steve Lavender.

Other Water Survey staff were involved in support functions or advisory capacities. Word processing was performed by Kathleen Brown and Lynn Weiss. Illustrations were prepared under the supervision of John Brother, Jr. Statistical evaluation of data was reviewed by Krishan P. Singh, Principal Scientist. Equipment for sediment oxygen demand measurements, instruction in its use, and evaluation of test results were provided by Thomas Butts, aquatic biologist. The wet-dry fallout sampler was made available through Richard G. Semonin, Assistant Chief, and Donald F. Gatz, Head of Atmospheric Chemistry Section.

Constituent analyses of water samples were performed by the IEPA laboratory in Champaign under the direction of Roy P. Frazier. Wendy Blake Coleman of IEPA in Springfield served as contract manager and conducted the IEPA efforts in biological assessments of the stream system.

The Urbana-Champaign Sanitary District provided physical access and electrical power to a stream monitoring station located on its property. The District also supplied all records of effluent quantity and quality requested by ISWS. The Electrical Engineering Department of the University of Illinois was similarly generous in supplying electricity and providing access to a storage room near the urban stream for use as an equipment shelter. Authorities of the City of Urbana and Champaign County reviewed and approved plans for site installations. The District Office of the U.S. Geological Survey in Urbana supplied the flow rating curves for two sites and loaned equipment to IEPA and ISWS when an emergency occurred during one of the special sampling efforts.

The authors are grateful to all of the above for their contributions to the project.

SECTION 2

STUDY AREA

GEOGRAPHY, HYDROLOGY, AND CLIMATOLOGY

The study area for the analysis of the impact of urban runoff on receiving streams is in the east central portion of Illinois. This is an area characterized by relatively flat topography which is rather poorly drained. The soils are basically silts overlying till or outwash plains. Tributaries to the upper reaches of three rivers, the Embarras, the Kaskaskia, and the Vermilion, receive drainage from the Champaign-Urbana area. These rivers are little more than agricultural drainage ditches at their headwaters, with the bulk of their flow during dry periods being derived from groundwater seepage and field drainage tiles.

The drainage network that was the focus of this study is the often-studied Boneyard Creek and its receiving stream, the Saline Branch of the Vermilion River. The Boneyard watershed contains parts of both Champaign and Urbana. Both cities' central business districts are in the watershed, along with commercial, industrial, and residential properties, and the bulk of the main campus of the University of Illinois. The stream is used as an urban drainage ditch, being channelized over most of its course to improve hydraulic efficiency. Several city blocks have been built over the channel, which is enclosed in a rectangular concrete culvert in these areas. Dry weather flows in the Boneyard are generally in the range of 3-5 cubic feet per second (cfs) in its lower reaches. The drainage area at the confluence with the Saline Branch is approximately 8 square miles, and the main channel length is about 3.7 miles.

The Saline Branch receives discharge from the Boneyard as well as some direct runoff from the Urbana area. The bulk of the 73.8 square mile watershed is agricultural, with dry weather flow upstream of Champaign-Urbana being derived from agricultural drainage. The channel tributaries in this area are generally improved drainage ditches. The main channel geometry of the Saline Branch is a fairly well defined trapezoidal section. The channel was straightened and cleared to move stormwaters more efficiently, since prior to improvements the low velocities in the Saline caused frequent flooding. Dry weather flows upstream from the urban area are often below 5 cfs. Just downstream from the point where the Boneyard enters the Saline Branch is the outfall of the Urbana-Champaign Sanitary District's Northeast Plant. The average treatment plant discharge is 19.5 cfs, though it occasionally drops below 8 cfs. Dry weather flow in the Saline Branch at the downstream end of the study area averages about 45 cfs, though it is sometimes less than 15 cfs.

The average annual precipitation in the Champaign-Urbana area is about 36.5 inches, including about 23 inches of snow (0.1 inch water per inch of snow). Precipitation as rainfall provides the bulk of the runoff in the streams, although snowmelt periods may provide high sustained flows in early spring. Rainfall in the study area is of two basic types, frontal and convective. Frontal precipitation is the predominant type from late fall through early spring and is typically widespread with relatively low spatial and temporal variations in intensity. This type of storm generally has a relatively long duration. Convective rainfall, by contrast, has a rather high degree of spatial and temporal variation in intensity, tends to be local, and is usually of rather short duration. Depth-duration-intensity curves are shown in figure 2.1.

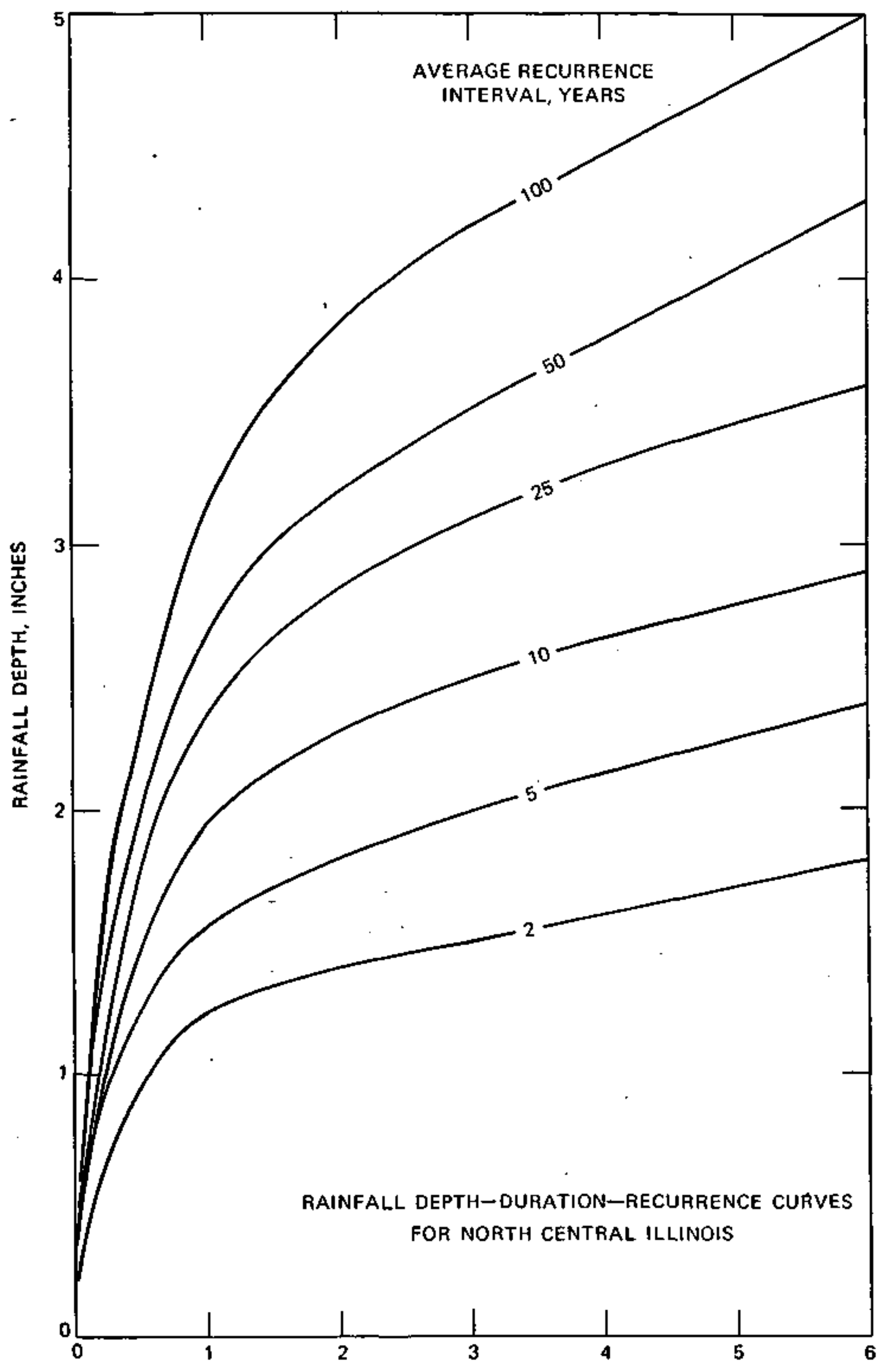


Figure 2.1. Rainfall relationships for Champaign-Urbana

SITE SELECTION

Site selection was influenced by several considerations: ease of access, power and telephone availability, hydraulic control for stream gaging, and the safety of equipment with respect to potential vandalism. Two monitoring sites in the urban watershed were desirable to provide quality assurance on the urban washoff data and to provide insurance that at least one set of samples would be available for the urban area if a local power or telephone failure or an equipment malfunction prevented sample collection at the other site. Three stations were necessary to monitor the receiving stream, one upstream from the urban inflow, one immediately downstream from the urban inflow, and a third downstream from the urban area and sewage treatment plant discharge. It was also desirable that these five sites be located so that the field crew could inspect all of them in a reasonable amount of time during an event. The final locations are shown on figures 2.2 and 2.3.

The upstream monitoring site on Boneyard Creek was placed at the USGS stream gaging station (3337000) on the University of Illinois campus. The water level sensor for the site was located in the gage house and the USGS rating curve was used. This site is referenced as number "2" on the basin map and in the following discussions. This sub-basin has a drainage area of 3.1 square miles, most of which is in the city of Champaign. The central business district of Champaign makes up 7.5 percent of the drainage area, and is nearly 100 percent impervious. Other city properties, including residential, commercial, and light industrial, make up an additional 81.2 percent of the sub-basin, and have been measured to be approximately 35 percent impervious.

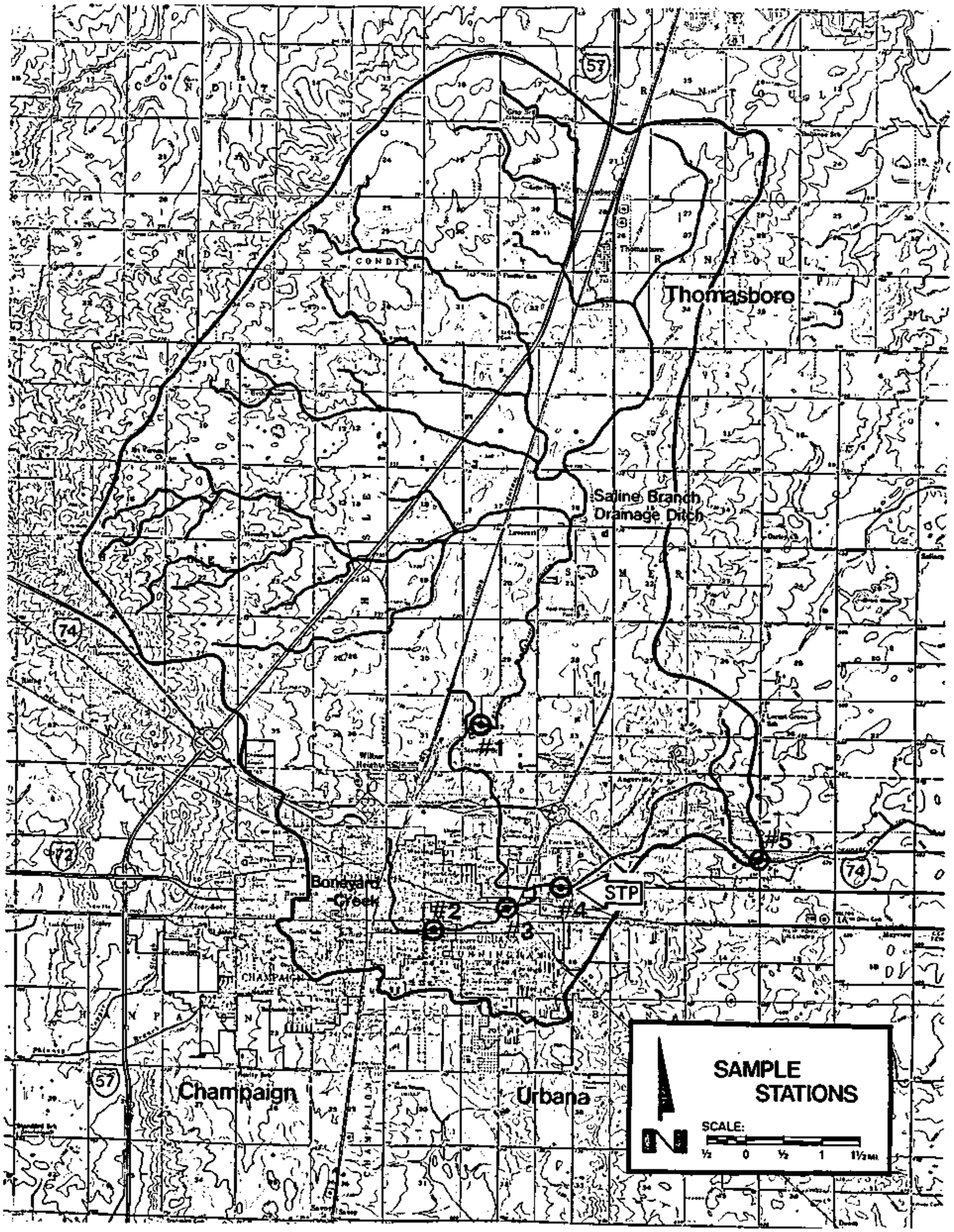


Figure 2.2. Champaign-Urbana NURP study area - drainage basins and sampling stations

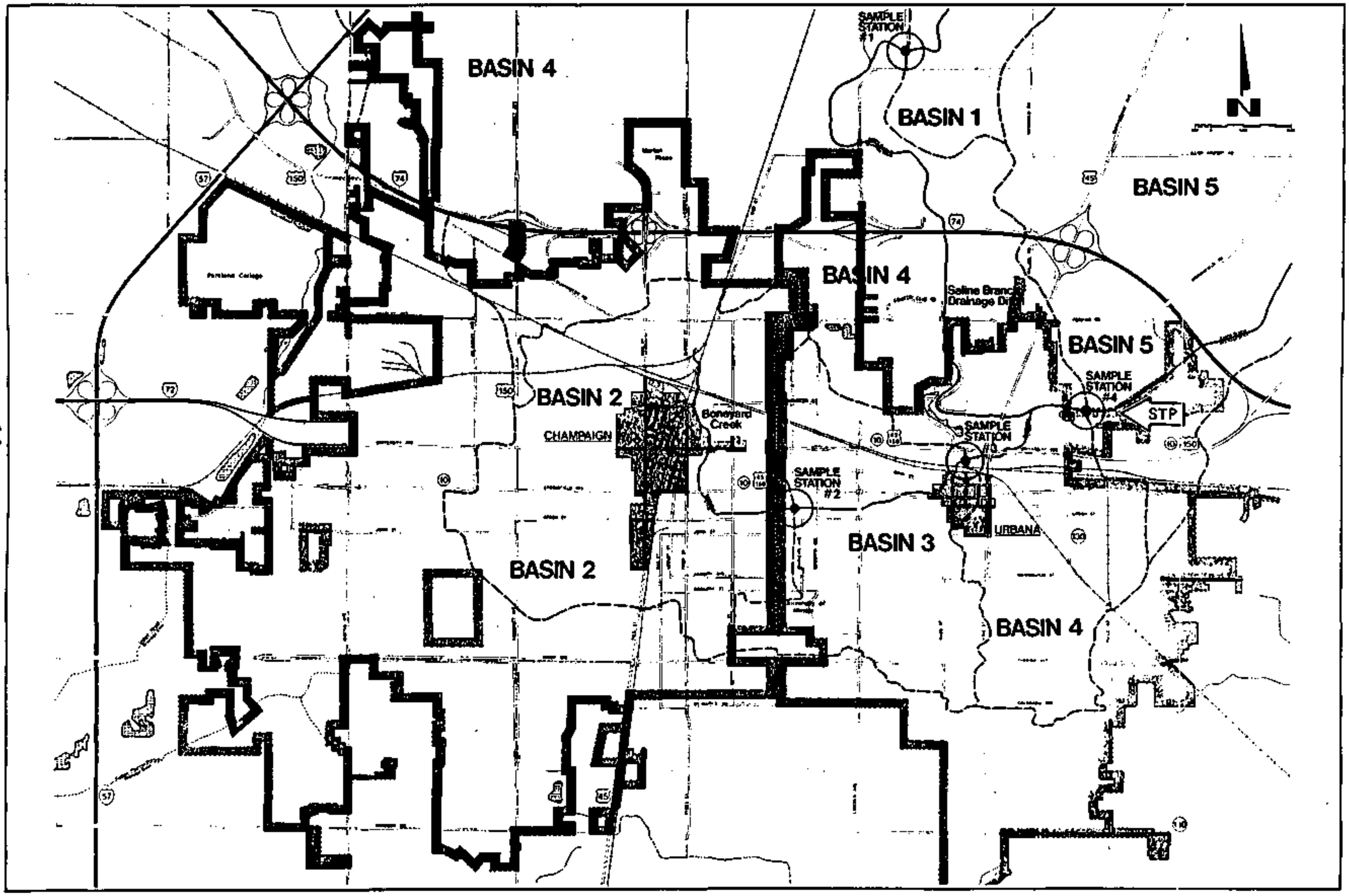


Figure 2.3. Champaign-Urbana NURP study area - detail of urban area

The second urban site, referred to as site number "3", was selected at the Broadway Avenue bridge in Urbana. An additional 1.76 square miles drain into the creek between this point and site 2. The central business district of Urbana makes up 3.1 percent of this additional drainage area, and is essentially 100 percent impervious. Other city properties account for 94.5 percent of the additional area, and are about 35 percent impervious. The main channel between sites 2 and 3 is about 3.5 stream miles in length.

The upstream site on the Saline Branch was designated as site number "1". In order to avoid any significant urban contributions at this site, the monitoring station was located about 3.6 stream miles above the mouth of Boneyard Creek at a county road bridge. Approximately 50.8 square miles of agricultural land drains to this site. This watershed contains about 240 lane miles of improved and unimproved roadways, and about 65 lane miles of interstate highway. The Village of Thomasboro, population 1200, lies in the upper end of the watershed.

Site number "4" was chosen at an abandoned USGS stream gage (3337500) about 0.3 miles downstream from the mouth of Boneyard Creek, 3.9 stream miles below site 1. The site consists of a concrete weir and gage house, both of which were utilized for the study. The monitoring station was about 500 feet upstream from the sewage treatment plant outfall. There is lateral drainage above this site of about 9.4 square miles which was not included in areas of sites 1 and 3. About 28.6 percent of this lateral area is inside the Urbana city limits, and is composed of residential, commercial, and light industrial properties. The remaining area is made up of agricultural, commercial, and residential properties. There are about

50 lane miles of improved and unimproved roadway outside the city limits, and about 9 lane miles of interstate highway.

Site number "5" was chosen at a county road bridge about 4 miles downstream from site 4. The average time of travel between sites 4 and 5 ranges between 80 and 120 minutes, depending on stream stage and seasonal streambank cover. Lateral drainage between this site and site 4 adds approximately 7.5 square miles of drainage area, including about 3.9 percent city property and 96.1 percent urban fringe that includes farms, woodlots, private residences, strip commercial area, the sanitary plant, and the Champaign County landfill. Site inspection of the landfill and a field check of the 4-mile stream reach indicated no surface drainage from the landfill to the Saline Branch. Table 2.1 summarizes these and other data for the five sub-basins.

UCSD NORTHEAST SEWAGE TREATMENT PLANT

The cities of Champaign and Urbana are jointly served by the Urbana-Champaign Sanitary District. The District operates two treatment plants, one southwest of Champaign, the other northeast of Urbana. The southwest plant serves an area of residential and scattered strip commercial land uses with a population equivalent of 24,000. This plant discharges to a tributary of the Kaskaskia River away from the study area. The northeast plant, which discharges directly to the Saline Branch, serves a population equivalent of 90,000, including both residential and commercial/industrial areas of the two cities. The design capacity of the plant is 34.6 million gallons per day (mgd), with a design mean flow of 17.3 mgd. The influent sewer lines are arranged to separate the residential and commercial sewage. The design average inflow from the predominantly residential areas is 11

Table 2.1. Fixed Site Data for Boneyard Creek and Saline Branch Sites

ITEM	SUB-BASIN 1	2	3	4	5
Stream Name	Saline Br	Boneyard	Boneyard	Saline Br	Saline Br
Basin Area, Total (sq mi)	50.84	3.14	4.90	66.27	73.77
(Non-Urban)					
Roadway Length (lane-mi, based on 12 ft width)	200.0	-	-	263.4	336.5
Roadway Impervious Area (sq mi)	0.45	-	-	0.60	0.77
Urban Area (sq mi)	0.58	3.14	4.86	9.73	10.56
Central Business Dist. (sq mi)	0.00	0.32	0.38	0.42	0.42
Impervious Area (sq mi)	0.16	1.31	1.95	3.60	3.95
Total Impervious Area (sq mi)	0.61	1.31	1.95	4.20	4.72
(percent)	-	41.72	39.80	6.34	6.40
Pervious Area (sq mi)	50.23	1.83	2.95	62.07	69.05
Soil Type (ABCD)	B	B	B	B	B
Available Water Storage (in/in)	0.45	0.45	0.45	0.45	0.45
Permeability Soil Horizon (in/hr)	1.30	1.30	1.30	1.30	1.30
Erodibility "K" Factor (USLE)	0.37	0.37	0.37	0.37	0.37

mgd, and from the commercial area is 6.3 mgd. These flows are treated separately in the plant until they reach the effluent stage, at which time they are mixed. Each inflow is first passed through a grit chamber and barminutor to remove suspended inorganics, to screen out large objects, and to shred floating material. Both flows then proceed to their respective primary clarifiers. At this stage, settleable solids and floating material are transferred to primary sludge digesters. Approximately 35 percent of the influent organic load has been removed by the time the flow leaves primary treatment.

Secondary treatment of the residential portion of the flow is accomplished by an activated sludge process. Flow is pumped from the primary tank to contact aeration tanks, and then to final clarifying tanks. Sludge settling out in the final tanks is recycled either through the reaeration tanks or to the primary tanks.

Secondary treatment of the commercial flow utilizes a trickling filter process. Effluent from this process goes to final clarifiers to allow sludge to settle out. This sludge is returned to the primary tanks and eventually to the primary sludge digesters.

After secondary treatment, 90 percent of the original organic load has been removed from the wastewater. Part of the effluent may be mixed with the incoming flow to maintain the design flow, while the remainder is discharged to the Saline Branch. Chlorination of the plant effluent once was routine but had been discontinued prior to the study.

WEATHER DURING THE STUDY PERIOD

The Water Year 1982 was slightly wetter and cooler than normal. For the twelve-month period from October 1981 through September 1982, the total rainfall was 38.44 inches, including 64.0 inches of snow. The temperatures for the same period showed an average daily value of 49.4°F. The normal statistics, as compiled by State Water Survey staff from records dating back to 1889, are 36.5 inches of rainfall per year, including 23.0 inches of snow. The normal daily average temperature for a year is 51.7°F.

Seasonally, the fall of 1981 was cooler and dryer than normal, although the snowfall was greater than normal. The winter of 1982 was cooler and wetter than normal, with above average snowfall. The spring of 1982 was cooler and wetter than normal, and the summer was cooler and dryer than normal.

Year	OBSERVED PRECIPITATION		NORMAL PRECIPITATION		OBSERVED TEMPERATURE (°F)			NORMAL TEMPERATURE (°F)		
Month	Rain	Snow	Rain	Snow	Max	Min	Mean	Max	Min	Mean
1981										
Oct	2.82		2.59		62.2	41.8	52.0	66.2	44.0	55.1
Nov	1.27		2.56	1.80	52.0	34.8	43.4	49.9	32.4	41.1
Dec	2.32	18.5	2.26	4.7	33.1	19.4	26.3	37.8	22.7	30.2
1982										
Jan	5.79	22.2	2.12	5.8	24.7	6.5	15.6	34.1	18.2	26.1
Feb	1.33	9.0	1.92	5.4	30.7	16.9	23.8	37.0	20.7	28.9
Mar	3.18	2.3	3.21	4.4	46.4	31.1	38.8	48.5	30.4	39.5
Apr	2.45	6.6	3.65	0.7	56.8	36.6	46.7	61.8	40.9	51.3
May	6.50		3.93		79.4	57.2	68.3	72.6	51.1	61.8
Jun	3.57		4.00		76.9	57.3	67.1	82.1	60.5	71.3
Jul	4.96		3.57		84.1	66.4	75.3	86.2	64.3	75.2
Aug	2.77		3.40		80.5	60.9	70.7	84.1	62.4	73.2
Sep	1.48		3.18		76.0	54.5	65.3	78.0	55.3	66.7
Total	32.03		36.44		Mean		49.4			51.7

SECTION 3

METHODOLOGY

The primary aim of the data collection effort was to measure the production of urban pollutants during storms and to determine their progress through the drainage system as the urban runoff entered the receiving stream and subsequently flowed out of the study area. A computer-controlled data collection network was employed to monitor rainfall and runoff quantity and quality at the five sites previously described. Additional wet-weather efforts included discharge measurements at the unrated sites and manual stream sampling to supplement or replace automated sampling. In dry weather, stream samples were collected at the sites to establish background constituent levels in low flows. Tests of sediment oxygen demand, particle size distribution and constituent concentration in sediment, and diurnal fluctuation of dissolved oxygen, along with habitat assessments and inventories of fish and macroinvertebrate populations were also run on the receiving stream. These results were used in forming basic statements about overall stream conditions and differences in environment upstream and downstream from the source of urban pollutan s.

DATA COLLECTION

The details of hardware used in the automated data collection system are put forth in the final report of the street sweeping evaluation study.[1] Several changes were required for its implementation in this work. The principal features of this telemetry network were a central station, consisting of a minicomputer, dual floppy disk drive and interface, and remote electronic stations at each field site. Telephone lines were the communication links between the central and remote stations.

Along with a telephone line, electrical power (120 volt AC) was required at each site to supply the needs of the remote station and the monitoring equipment. Each site was equipped with a refrigerated automatic sampler and a continuously reporting water level sensor. The latter device was a potentiometer connected to a pulley on whose track a counterweighted float was suspended from a steel tape in a stilling well. The potentiometer range of 0-5 volts corresponded to a stream stage range of 0-10 feet. The potentiometer was zeroed on the lowest point in the surveyed cross section, so that the water level reported by the station would be the actual stage in the rated section. The automatic samplers had the capacity for 24 500-ml discrete samples and accepted signals to sample from the remote station. Tipping bucket raingages were installed as part of the automated system at sites 1, 2, and 4. Each bucket tip represented 0.01 inch of rainfall, and the tips were accumulated by a board in the remote station. A self-controlled wet-dry fallout device was installed at site 2 to collect rainfall samples during events without contamination of dustfall during dry periods between events.

The monitoring program RUNOFF developed earlier[1] was modified for use in this study. The two operational modes, WAIT and EVENT, were preserved. In WAIT mode, rainfall accumulator registers at the three stations equipped with raingages were interrogated on a one-minute interval. If no rain was detected, hourly summaries of the water levels at the sites were printed at the computer terminal. None of the data were written to disk storage. If 0.02 inch of rain was detected within a 30-minute span at any site, EVENT mode took control. Under this mode, interrogations were made every minute for water levels and rainfall accumulations. These data were written to disk storage and a printout of current conditions at the sites was issued at the terminal every five minutes. Water levels were compared at every interrogation to programmed criteria for the sites, and samples were ordered at any site as soon as the reported level exceeded its criterion. For most of the year, after the first sample had been taken, additional samples were ordered at five-minute intervals at sites 2, 3, and 4 and at ten-minute intervals at sites 1 and 5. In July, when the flow at site 1 was very low and rarely changed significantly during an event, its sampling interval was extended to 30 minutes for economy. A version of RUNOFF which doubled the sampling interval after the eleventh sample and tripled it after the seventeenth was used for most of the season. Sampling at a site continued until the sampler capacity was exhausted or the water level dropped below the minimum for the site. An event was declared to have ended when there had been no increase in the rainfall totals for 90 minutes and the water level at site 5 had dropped below a pre-set value.

As soon as possible after the end of an event, the samples were retrieved from the sites and the system was reset for the next event. Samples for laboratory analysis were selected to represent the event fully at each site. Proper representation of the rising, peak, and declining flow generally required eight to twelve samples from each site, half to be analyzed for solids and half for metals and nutrients. The full set of constituents analyzed is shown in table 3.1.

The rainfall record at site 2 was taken to represent the rain total over the Boneyard Creek basin for most events. However, the records of the U.S. Weather Bureau recording gage at the Morrow Plots on the University campus and a tipping bucket raingage on the roof of the Water Resources building near site 2, both operated by ISWS, were used to supplement the site 2 record when necessary.

Table 3.1. Maximum Constituent List for Stormwater Sample Analyses

Constituent	Abbreviation
Total Suspended Solids	TSS
Total Dissolved Solids	TDS
pH	pH
Specific Conductance	SC
Sulfate	S04
Chloride	Cl
Nitrate plus Nitrite Nitrogen (as N)	N03-N
Ammonia Nitrogen (as N)	NH3-N
Kjeldahl Nitrogen (as N)	TKN
Phosphorus (as P)	P
Chemical Oxygen Demand	COD
Lead	Pb
Copper	Cu
Iron	Fe
Chromium	Cr
Cadmium	Cd
Manganese	Mn
Nickel	Ni
Calcium	Ca
Magnesium	Mg
Sodium	Na

Laboratory determinations were of total concentrations of all constituents

Two important manual data collection efforts, discharge measurement and manual runoff sampling, were conducted in wet weather throughout the season. Theoretical stage-discharge rating curves had been developed for sites 1, 3, and 5 after surveys of the sites at the time of installation. Discharge measurements were made in accordance with U.S. Geological Survey (USGS) procedures during storms,[2] when the water levels were briefly high. From 11 to 15 measurements were made at each of the three sites and the results used to adjust the theoretical rating curves. The USGS suspended sediment sampling technique[3] was also used during storms, for the collection of vertically and horizontally integrated flow samples. Such samples were considered more representative of the flow than fixed-intake automatic samples. These samples were taken simultaneously with automatic samples to determine how well the automatic device sampled the flow.

Several field operations were scheduled during dry weather. Discharge measurements and manual stream sampling as described above were also carried out on dry days when the flow was low. Sediment Oxygen Demand (SOD) tests were run at 14 locations on the Saline Branch. Three tests each were done at or near sites 1, 4, and 5, along with one upstream from site 1, one between sites 1 and 4, one between sites 4 and 5, and two at separate locations downstream from site 5. The test, whose procedure is thoroughly outlined in ISWS Circular 129,[4] is a measure of the oxygen-consuming capacity of benthos in a stream or lake. Samples of stream bottom material at sites 1 and 5 were taken for determination of particle size distribution of all solids and analyses of constituent concentrations in material smaller than 63 microns (μ). The latter samples were collected in accordance with IEPA guidelines on sediment sampling.[5] IEPA also conducted three special studies on the streams: 1) an inventory of macroitivertebrates in the bottom materials at all sites; 2) an inventory of fish populations at sites 1 and 5; and 3) a 24-hour diurnal dissolved oxygen test at sites 1, 3, 4, and 5. All these data were considered essential in representing the physical, chemical, and biological characteristics of the streams and in identifying the differences in the Saline Branch between the sites upstream and downstream from the major source of urban runoff pollutants.

One additional set of data was supplied by the Sanitary District. Monthly values for minimum, maximum, and average effluent flow and constituent concentrations were available from IEPA, but the District opened its files so that daily averages of effluent flow rate, TSS, B0D5, and NH3-N could be retrieved by ISWS. Continuous flow records of plant effluent were also provided so that hourly fluctuations of flow on days of storms could be determined. These records were used in evaluating the influence of the treatment plant on the wet weather and dry weather observations at site 5.

DATA MANAGEMENT

The hydrologic data collected by the automated system during events were written to disk storage at the central station. When an event was over, the data were read from disk and transmitted through a conventional terminal-telephone link to the project file RAWDAT on the University of Illinois Cyber 175 computer. Except for some format changes, the system operations with event data and with RAWDAT on the Cyber were fundamentally the same as those developed for the street sweeping evaluation study and described in its final report.

The data management program MANAGE was again used to convert the raw data for an entire event to individual event files for each site. Though the format was changed considerably to reduce waste of storage space, each event file contains all information recorded at a site during the event. This includes one-minute records from start to finish of time and rainfall; flow derived from one-minute stage records and the site rating curve; indications of sampling times; analytical results for stream samples kept; and comments on the data or the event. From these files the event mean concentration (EMC), the flow-weighted average value for the entire event of each sampled constituent, was calculated. For sites with raingage records, rainfall statistics for each event were also calculated, as were flow rate and volume statistics for all sites. The load of each constituent was calculated as the product of flow volume and EMC for the event. These values are tabulated and summarized in Appendix I. Fixed site data and event data have also been transmitted to STORET.

EVENT MEAN CONCENTRATION CALCULATION

Event mean concentration (EMC) values were calculated according to the following equation:

$$EMC_j = \frac{\sum_{i=1}^{n-1} [C_{j,i}\ Q_i + C_{j,i+1}\ Q_{i+1}]\ \Delta t/2}{\sum_{i=1}^{n-1} [Q_i + Q_{i+1}]\ \Delta t/2} \qquad (3.1)$$

where EMC_j = event mean concentration of parameter "j"

$C_{j,i}$ = instantaneous sample concentration for time "i", and parameter j

Q_i = instantaneous discharge at time i

Δt = time between samples, in seconds

In order to assure that the event mean concentration data were in a consistent form to allow comparison from site to site, it was necessary to provide similiar time frames for each site for each event, to assure that the comparisons of the urban stormwater runoff loads with the receiving stream loads were for appropriate periods of time. This required the plotting of each site's data, selecting correct start and end times for the urban runoff event at site 3, and, considering lag times and hydrograph attenuation in the receiving stream, determining the appropriate start and end times at the other four sites.

Figures 3.1-3.4 show the hydrographs and observed TSS and lead concentrations at the five sites for the event of June 28. The event start and end times for site 3 were chosen as 1222 and 1538, respectively. A seven-minute lag was indicated between sites 2 and 3, so the assigned start and end times for site 2 were 1215 and 1530. Inspection of the site 4 hydrograph indicates a fifteen-minute lag time from site 3. There is a modest amount of attenuation at site 4 with respect to peak discharge, but the recession limb of the hydrograph lags an additional 1-2 minutes, allowing the same duration of 195 minutes for the urban runoff-related portion of the hydrograph to pass the site at start and end times of 1237 and 1552 respectively.

The analysis of site 5 data was the most difficult because of a) the higher baseflow, sustained by the sewage treatment plant effluent, b) the attentuation of the peak flow through the four-mile reach between sites 4 and 5, and c) the time lag between sites 3 and 5. This 88 minute lag requires a start time of 1350, while the event end time of 1820 was determined by comparing the urban storm-related runoff volume at site 4 to that at site 5 and accounting for the baseflow volumes.

The start and end times at site 1 were in all cases determined to relate to those at site 5 rather than those at site 3 in order to account for the possibility that rising stages at site 1 might need to be considered in the baseflow at site 5. For the event of June 28, these times were 1147 and 1617, respectively.

As can be seen in the figures, the periods of increased flows were well sampled at sites 2 through 5, but data were not collected near the hydrograph tails. In order to fully estimate the constituent loads at these times, a subjective analysis of the data led to approximate concentrations at the tail end of the event hydrographs in order to better estimate the water quality conditions in the streams. At this point, the data were considered to be ready for analysis. All events of the data set were analyzed in this manner.

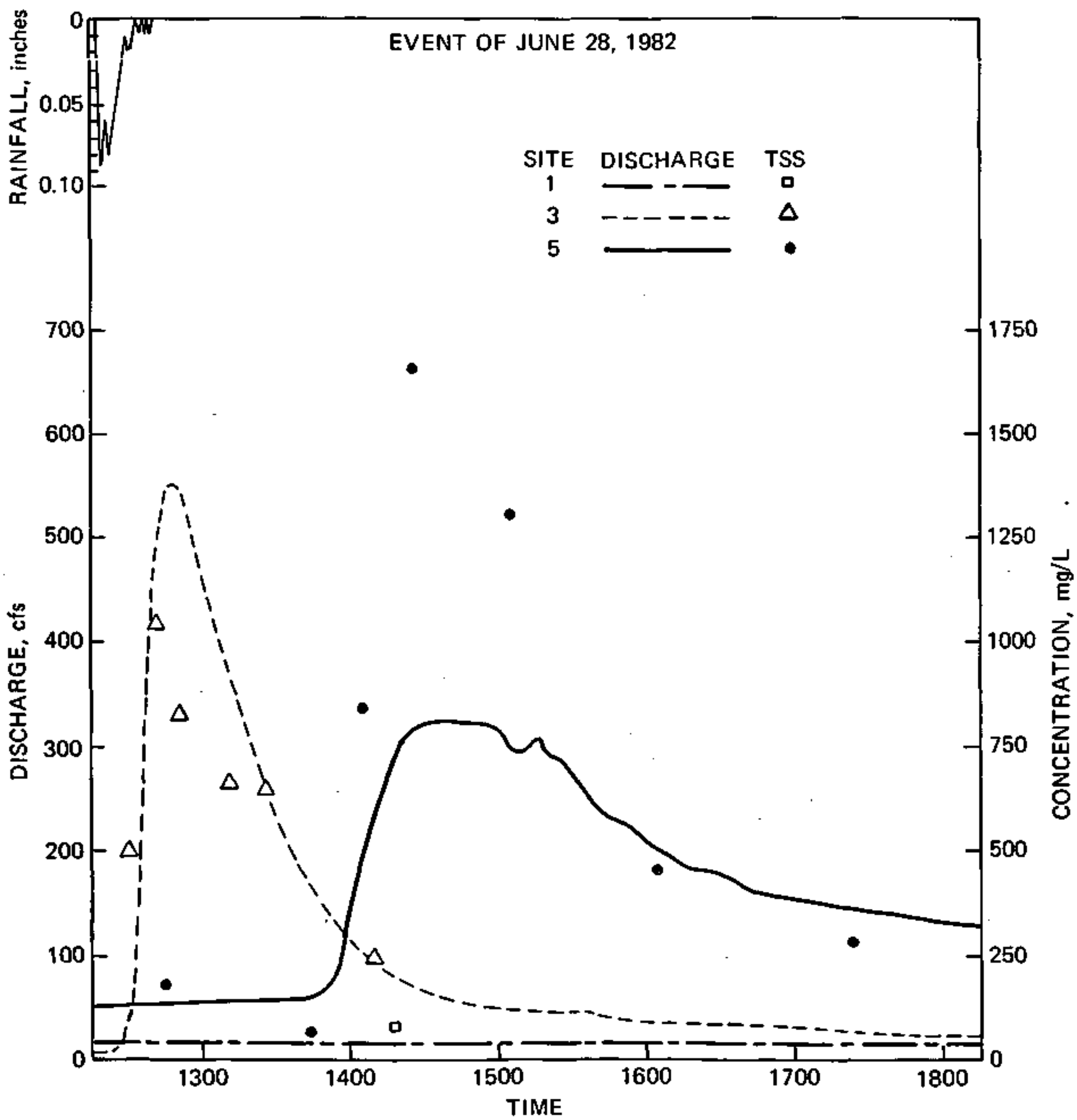


Figure 3.1. Hydrographs and TSS concentrations for event of June 28, 1982 at sites 1, 3, and 5

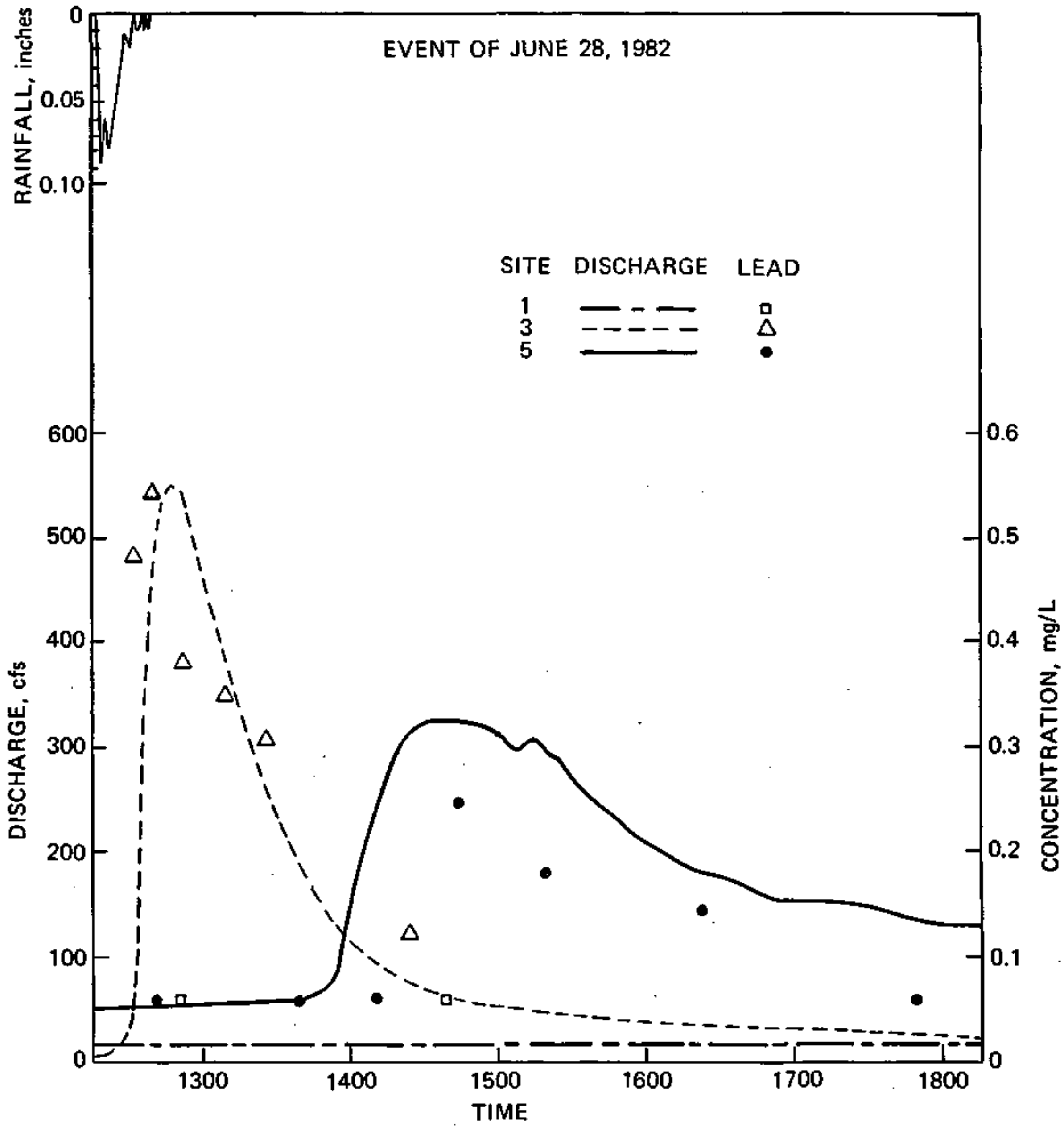


Figure 3.2. Hydrographs and lead concentrations for event of June 28, 1982 at sites 1, 3, and 5

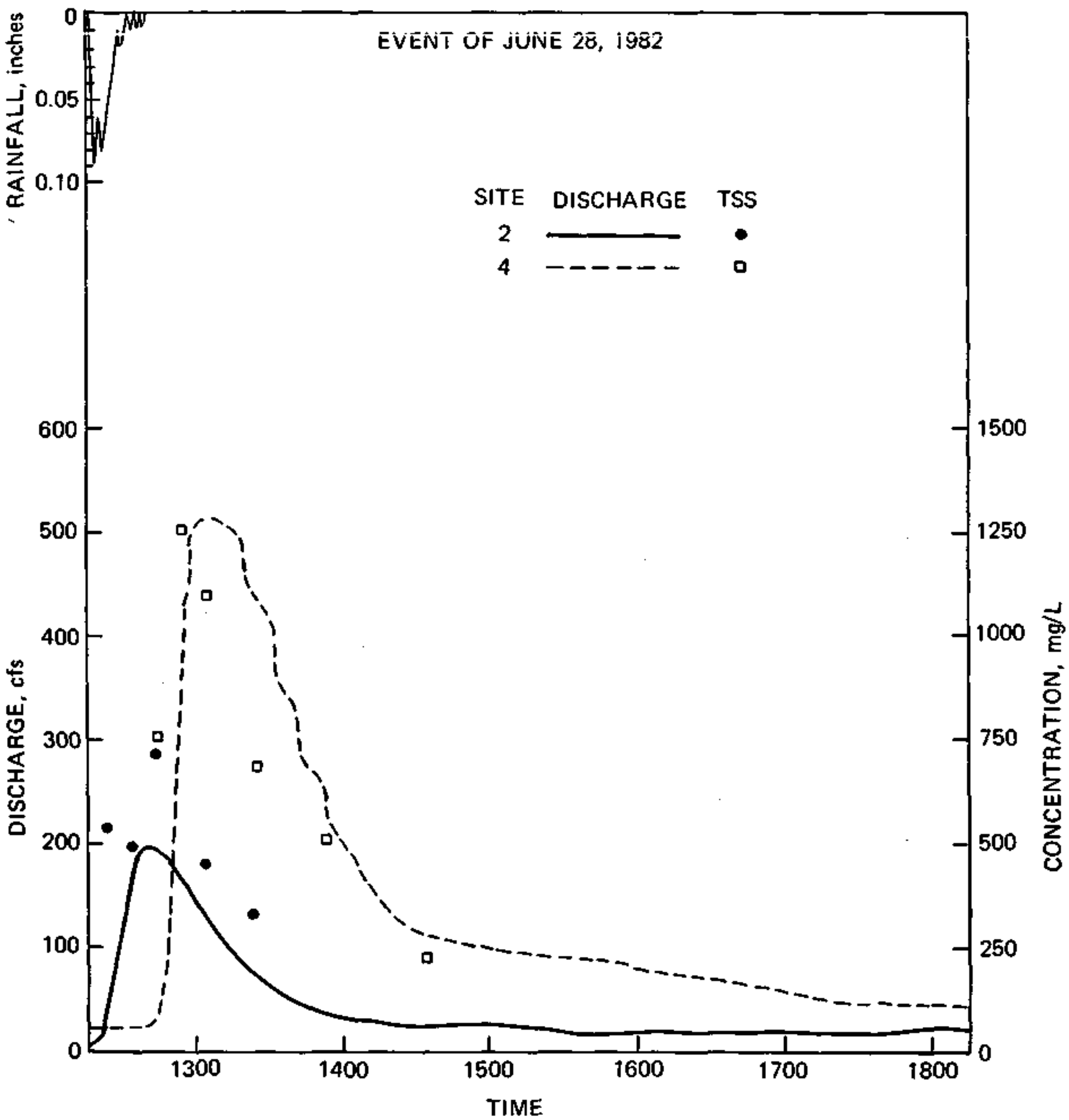


Figure 3.3. Hydrographs and TSS concentrations for event of June 28, 1982 at sites 2 and 4

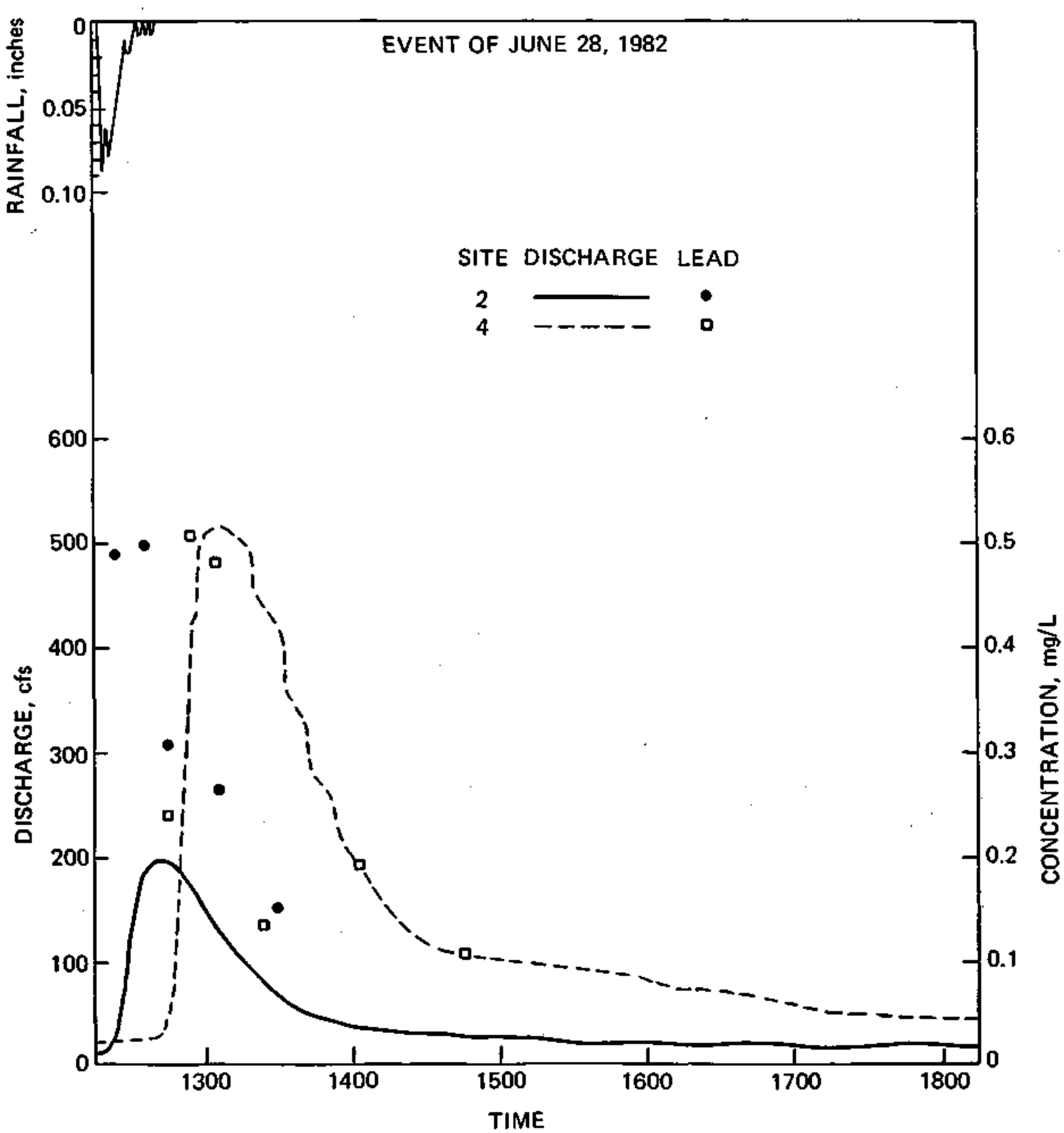


Figure 3.4. Hydrographs and lead concentrations for event of June 28, 1982 at sites 2 and 4

SECTION 4

QUALITY CONTROL/QUALITY ASSURANCE

FLOW RATING

USGS rating curves were used for sites 2 and 4. Although there was some question as to the accuracy of the site 4 curve due to some deterioration of the weir invert, it was determined that the errors associated with the deterioration were insignificant.

The rating curves for the other three sites were developed by SWS using field data collected in 1981. Each site was rated for several flows using a portable velocity meter. The resulting data was utilized to calibrate the theoretical curves. The rating curves for all five sites are shown in figure 4.1.

In order to periodically check the performance of the depth sensing devices in the telemetry system, wire weights were obtained from USGS and installed at each site. During times when the telemetry was out at a particular site, the wire weights also provided stage data to be used with grab samples.

Inspection of the results for sites 2 and 3 on the Boneyard Creek show greatly different discharges and total runoff volumes for the sites. Peak discharge is two and one half times greater at site 3 than at site 2 although the contributing area is only fifty percent greater. To confirm these results, the ILLUDAS model was applied to the Boneyard Basin using the June 28, 1982 rainfall. The model had been calibrated during the urban stormwater management study for Champaign-Urbana[6] performed in 1977-78. The fifteen-minute discharges obtained from the model run are plotted against the observed hydrographs in figure 4.2. The simulation results

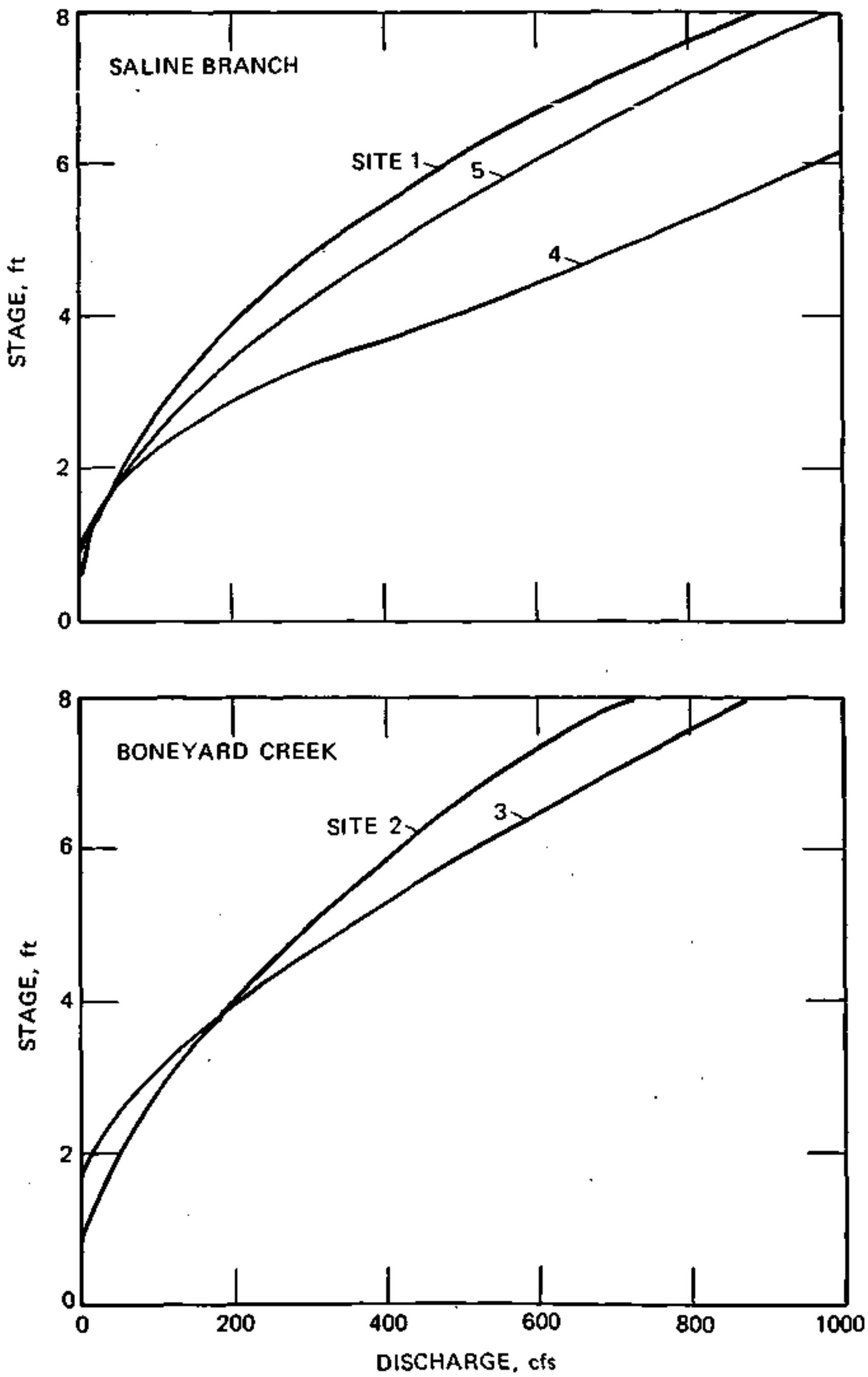


Figure 4.1. Rating curves for sampling sites

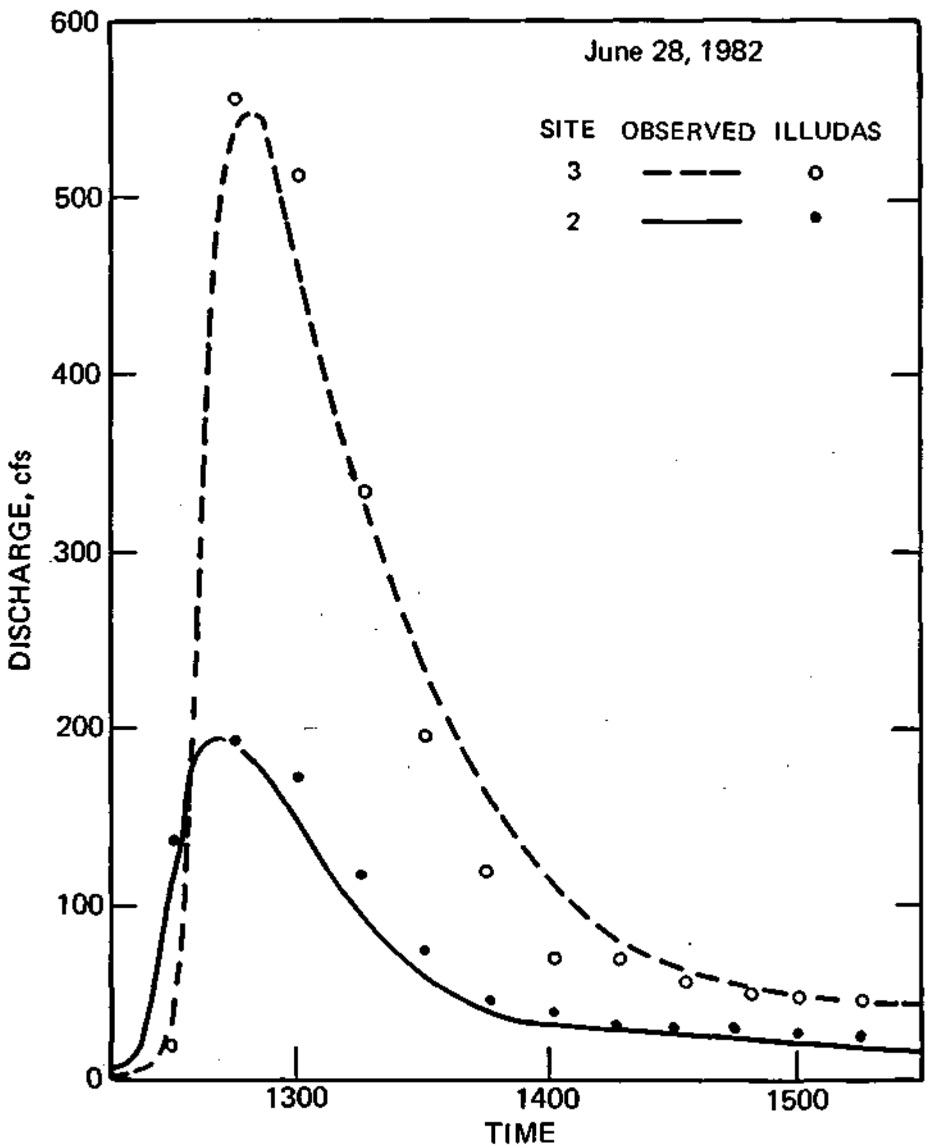


Figure 4.2. Observed and simulated hydrographs for Boneyard Creek sites for event of June 28, 1982

confirm the different response of the two basins and also provide some verification of the rating curves for the Boneyard Creek sites.

SAMPLER EVALUATION

The performance of the automatic samplers in representing streamflow was evaluated by two tests during the project. Concern over sampler performance was based on a fundamental problem inherent in site installation. The intake line of a sampler pump was attached to a perforated stainless steel pipe mounted at a fixed position in the stream. Ideally the intake would have been located at midstream. However, the need to stay within the lateral distance and head limits of the sampler pump and the need to avoid damage or fouling of the intake by debris resulted in the installation of the intake near the stream bank or at a bridge pier for four of the five sites. The intakes also had to be placed low enough to permit sampling at the first increase in stream level, so that they were very low in the stream profile at high flows. The concern then was whether a sample collected through an intake fixed at one point in a stream cross section was generally representative of the entire flow at the section.

The first test was the collection of two consecutive automatic samples at a site for dry weather flow and for each sample during a storm. It had been noticed in results from events in March and April that TSS concentrations in the first samples ordered at some sites, especially site 1, were unreasonably high. This became apparent when subsequent samples, taken from similar stream flows only 10 to 20 minutes later, showed much lower TSS levels. The only site for which this phenomenon was not observed was site 2, where the sampler intake was out of the water at low flow. Other constituents appeared to be unaffected. Therefore in June and July, duplicate automatic samples were collected at low flow for the other four sites and analyzed for TSS. Manual depth-integrated samples were taken simultaneously at midstream. Results are given below:

		TSS		
Site	Date	First sample	Second sample	Manual sample
1	6/9	1736	264	60
	7/9	360	132	100
3	7/9	318	11	3
4	6/14	470	90	34
	7/9	60	22	28
5	7/9	186	31	18

In all cases the TSS concentration of the second sample, taken immediately after the first, was much lower than that in the first and much closer to the level reported for the manual sample. In an extension of this test, duplicate samples were taken at the same four sites for each sampling instruction issued during the event of July 10. The first pair of samples were analyzed for TSS, and the results of the analyses are reported below:

Site	TSS First Sample	TSS Second Sample
1	396	100
3	336	356
4	312	528
5	130	100

For sites 1 and 5 the concentrations in the second samples again were lower than in the first, though the differences were not as dramatic as they had been in the low flow samples. This may have been due to the running of the samplers the previous day for the duplicate dry weather flow samples. For sites 3 and 4 the concentrations in the second samples were higher than those in the first, probably due to rapidly changing stream flows and concentrations in the early part of the storm.

These results suggested two possibilities: either the sampler intake was functioning as a trap for suspended sediment in the stream between events, or material was remaining in the intake line from the last prior run of the sampler. Whichever was the case, the accumulated material was not being cleared out of the line by the purge which preceded sampling, but only by the first complete sampling cycle. A decision not to use the first sample from any site for water quality analysis had actually been made based on the spring event data, before any of these test results were known. The findings of the test affirmed that decision. They also led to an alteration in the procedure for analyzing the data from the early events; for any event file containing the TSS concentration for a first sample, the value was examined and adjusted before average concentrations and loads were calculated.

The second test was a direct comparison of stream samples collected automatically and manually in wet and dry weather. Horizontally and vertically integrated manual samples were collected according to USGS procedure[3] simultaneously with automatic samples at sites 1, 3, 4, and 5 in dry weather, and at sites 3 and 5 during storms. Figures 4.3 and 4.4 contain the results of TSS analyses of all the samples. There are two plots, one for dry weather flow samples and one for storm samples. For each site, the TSS value for a manual sample is plotted against that for the matching automatic sample.

The results for the dry weather flow samples indicate a bias toward higher concentrations in the automatic samples. This was partly the

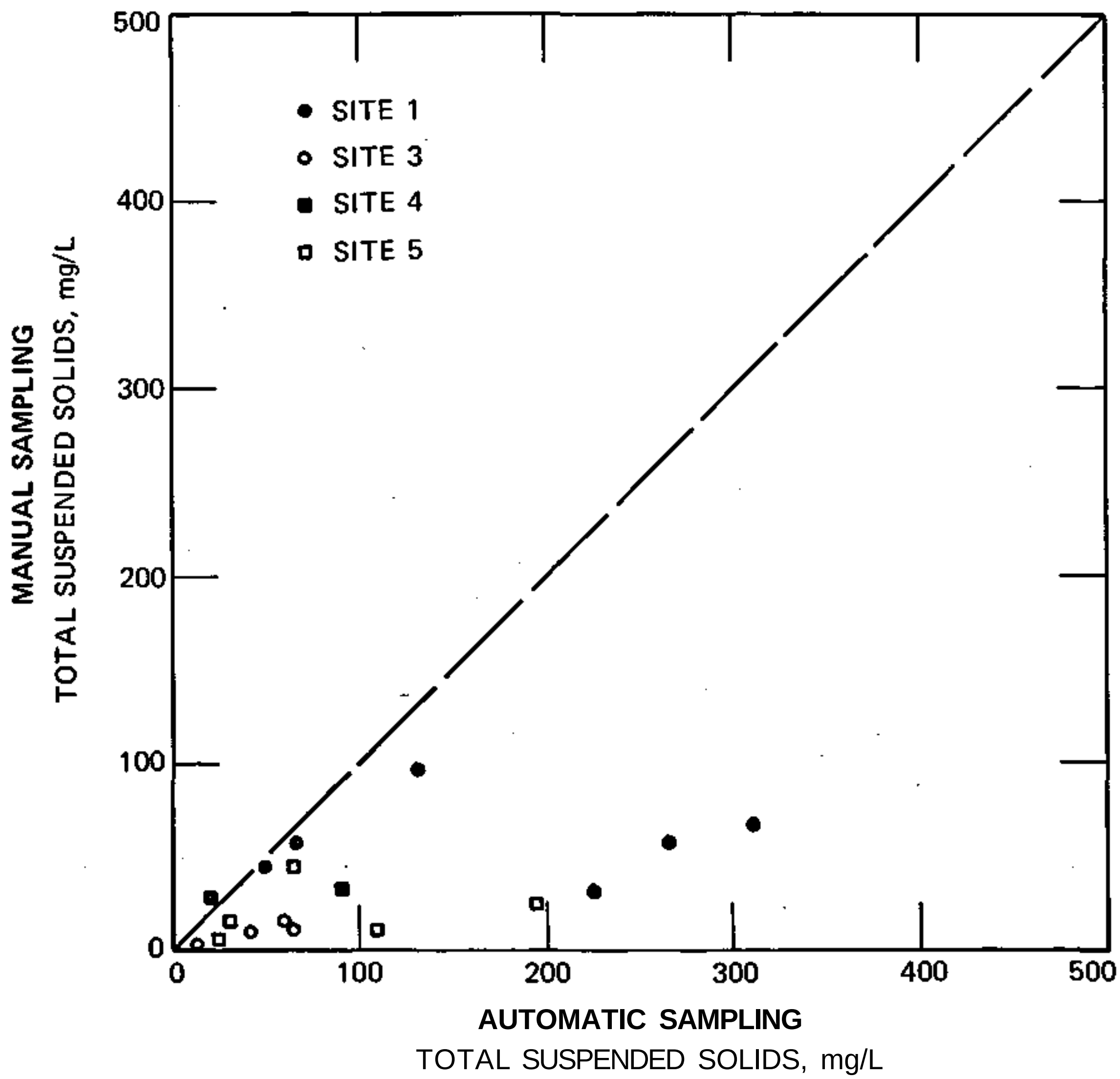


Figure 4.3. Sampler evaluation - dry weather flow samples

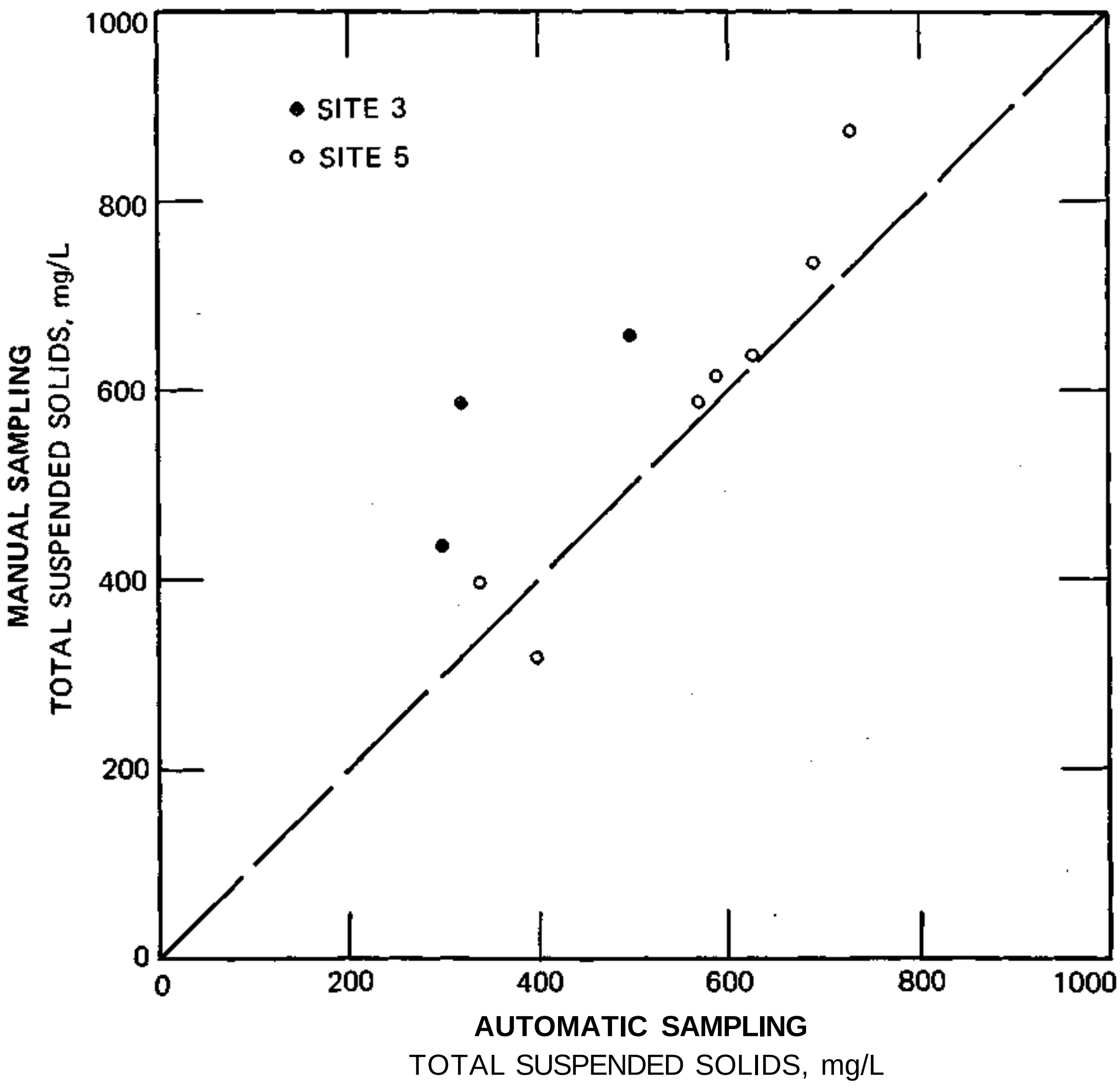


Figure 4.4. Sampler evaluation - storm runoff samples

product of the effect of sediment trapping or material accumulation in the intake lines described previously. It was also partly due to variations in flow velocity across the section, which can be relatively quite large during low flows. This in turn affected sediment carrying capacity of the stream. The result was a low flow that was not well mixed, in which sediment concentrations as well as velocities may have varied substantially across the section.

The plot for the storm samples shows the opposite result, with manual samples generally showing higher TSS concentrations than automatic samples. In these cases all concentrations were much higher than those in dry weather flow samples, and the mixing within the flow at the section was much more likely to be complete. The moderately lower values for some of the automatic samples may have been due to hydraulic effects of the culvert wall and bridge pier on which the intakes were mounted at sites 3 and 5. A drop in velocity near the intakes could have caused some corresponding decrease in sediment concentration in the flow. However, in general, the agreement in values was satisfactory.

The conclusions of this set of tests were the following:

1) use manual samples to represent dry weather flow;
2) do not use the first automatic sample in any event for water quality analysis;
3) accept the results of automatic sampling as representative of the flow during storm periods.

SECTION 5

RESULTS

DRY WEATHER FLOW

Streamflow samples were collected from all sites during periods of dry weather throughout the sampling season. From eight to thirteen samples were taken from each site, with most being analyzed for the full range of constituents in table 3.1. The means of analytical results for 14 constituents are presented in table 5.1. At all sites there were some constituents for which levels were reported only as below detection limits in one or more samples. In these instances, approximate values equal to 0.7 times the individual detection limits were used in the calculation of the means.

The table also contains entries for the sewage treatment plant effluent and for two stations of the IEPA ambient water quality monitoring network which are located on the Saline Branch within the NURP study area. The treatment plant effluent is sampled daily and analyzed for TSS, NH3-N, and B0D5. The values in the table for these constituents are means of results of the daily sampling for the entire period of the study. The phosphorus value for the treatment plant effluent is the average of 77 samples collected between 1971 and 1982 by IEPA in its waste effluent sampling program. The IEPA stations are BPJC-04, which coincides with NURP site 4, and BPJC-01, which is about 0.6 mile downstream from the sewage treatment plant outfall, at the point where the Saline Branch passes under Interstate Highway 74. The values in the table for these sites are means of results for all samples collected at the stations from 1972 to 1981. For BPJC-04 and BPJC-01 respectively, the numbers of analyses were 49 and

Table 5.1. Summary of Means - Dry Weather Flow Sampling

	TSS	TDS	SO4	CL	NH3-N	NO3-N	TKN	P	COD	Pb	Cu	Fe	Cr	Mn
NURP 1	65	389	37	28	.07**	8.3	.75	.09	17	.035**	.01	1.24	.007**	.08
NURP 2	5	489	70	47	.58	2.2	1.2	.29	12	.035**	.01*	.20	.007**	.06
NURP 3	8	540	89	45	.63	1.6	1.3	.34	12	.035**	.03*	.42	.06*	.08
NURP 4	24	491	63	37	.32*	6.9	.8	.16	11	.035**	.007**	.58	.02*	.07
BPJC-04	-	387	58	32	.32	7.5	-	.64	-	.019	.072	1.1	.002	.07
UCSD	15	-	-	-	8.5	-	-	8.3	-	-	-	-	-	-
BPJC-01	-	451	75	40	2.07	6.6	-	2.13	-	.009	.072	.9	.010	.09
NURP 5	22	465	68	41	2.9	7.5	4.2	3.4	21	.035**	.03*	.45	.01*	.05
Standards†		1000		500	1.5	10.0		0.5		.1	.02	1.0	.05	1.0

NURP 2 and 3 are on Boneyard Creek
NURP 4 and BPJC-04 are same site
UCSD is sewage treatment plant outfall

All values in mg/1
** All results below detection limit
* Some results below detection limit
† General use water quality standards

53 for TDS, NH3-N, N03-N, and phosphorus, and 12 and 11 for metals, sulfate, and chloride. It should be noted that the IEPA ambient water quality sampling is done according to a calendar schedule and does not represent dry weather flow exclusively.

Using a statistical procedure outlined in Steel and Torrie[7] to compare the means of samples with unpaired observations and unequal variances, the means for all constituents in the table were compared for all possible pairings of NURP sites. The objective of this analysis was to determine whether the means of any constituent for any two sites were significantly different at a 90% confidence level. Four pairings of sites were considered central to this analysis; they are identified and the results are given below.

Sites 1 and 3

Site 1 greater - N03-N, iron, TSS

Site 3 greater - NH3-N, TKN, phosphorus

Sites 1 and 4

Site 1 greater - COD, TSS

Site 4 greater - phosphorus

Sites 3 and 4

Site 3 greater - NH3-N, TKN, phosphorus

Site 4 greater - N03-N, TSS

Sites 4 and 5

Site 4 greater - none

Site 5 greater - NH3-N, TKN, COD, phosphorus

Examination of the comparisons of sites 1 and 3 to each other and to site 4 indicates that TSS levels at site 4 represent a mixing of the urban and rural concentrations to an average value. It likewise suggests that relatively higher concentrations of NH3-N, TKN, and phosphorus in the

Boneyard are diluted to some extent by the Saline, while similarly higher levels of COD and N03-N in the Saline are diluted by the Boneyard.

The major result of this analysis was the identification of large increases in concentrations of NH3-N, TKN, phosphorus, and COD from site 4 to site 5. The means of these four constituents for site 5 are two to nine times as great as those for site 4. This observation, corroborated by the results from IEPA station BPJC-01, strongly indicates the sewage treatment plant effluent as the primary source of these materials measured at site 5.

General use water quality standards in force during the project were exceeded for only three constituents, NH3-N (1.5 mg/1) at site 5, iron (1.0 mg/1) at site 1 and copper (0.02 mg/1) at sites 3 and 5. Phosphorus levels were high at site 5, but the general use standard does not apply to the Saline Branch in the study area. It should be noted that in October 1982, after data collection for this project had ended, the Sanitary District started up an NH3-N removal operation at the plant as a last treatment step prior to effluent discharge. This process reduces effluent NH3-N to levels well below 1.0 mg/1, so that the downstream concentrations indicated by data from the project are certainly greatly reduced now. It should also be noted that in December 1982 the general use water quality standard for NH3-N was revised. The current standard states that the total NH3-N in any stream shall not exceed 15.0 mg/1, and that if it exceeds 1.5 mg/1 then no more than 0.04 mg/1 may be in unionized form. While the breakdown of ionized versus unionized NH3-N was not available for data collected in this project, it is highly probable that the values observed in the NURP samples were within the new standard.

As the season progressed from spring to fall, the base flow in the system declined. Some of the constituents demonstrated behavior that appeared to be related to this change. Examination of the results of individual samples throughout the season at sites 4 and 5 showed that while TSS, N03-N, and calcium all progressively decreased, sulfate, chloride, NH3-N, TKN, phosphorus, GOD, chromium, manganese, and sodium increased. Whether this was due to the decline in flow, the change of season, or some other combination of factors is uncertain.

To ascertain whether the Saline was representative of other agricultural streams in Illinois, the average dry weather results from site 1 were compared with average values from four stations of IEPA's ambient water quality monitoring network. The station codes and locations are listed below:

CODE	LOCATION
BM-02	Sugar Creek in Edgar County near Indiana state line
BN-01	Brouillets Creek near Edgar Co. across Indiana state line
KCA-01	Bay Creek in Pike County near Nebo
PWB-02	Kilbuck Creek in Winnebago County near Rockford

The drainage areas above all four stations have only agricultural uses. The first two stations are in eastern Illinois, the third in western Illinois, and the last in the northern part of the state. The start dates of monitoring at the four sites range from 1958 for PQB-02 through 1972 for BM-02 and KCA-01 and up to 1978 for BN-01. The results of monitoring water quality at these sites are given in table 5.2 along with the average dry weather flow values from site 1.

In general the data from site 1 suggest that the Saline has rather high N03-N, rather low sulfate and phosphorus, and average levels of the other constituents reported for the agricultural basins in the IEPA ambient network. Since N03-N is not an urban pollutant of great concern, it is

Table 5.2. Average Dry Weather Flow Values, Site 1 vs.
Four Sites of IEPA Ambient Network

STATION	TSS	TDS	S04	C1	NH3-N	N03-N	P	Pb	Cu	Fe	Mn
NURP 1	65	389	37	28	<.10	8.3	0.09	<.05	0.01	0.5	0.08
BM-02	37	-	47	25	0.14	3.5	-	0.002	0.004	2.5	0.11
BN-01	59	346	54	23	0.10	5.7	0.23	0.002	0.015	0.4	0.07
KCA-01	103	255	25	17	0.40	1.3	0.41	0.008	0.014	4.1	1.70
PQB-02	36	382	59	22	0.12	6.9	0.15	0.047	0.056	0.9	0.15

All values in mg/1

reasonable to claim that, for the purposes of the study, site 1 fairly represents agricultural flow in Illinois and that it is not influenced by the presence of Thomasboro.

EVENTS

During the course of the twelve-month sampling period, data were collected for 59 of the 75 rainfall events having a minimum average intensity of 0.04 inch per hour. A total of 1075 samples from 31 of the 59 monitored events were analyzed for constituent concentrations. The results of monitoring and sampling these 31 events are summarized in table I.1 in Appendix I. The table shows the rainfall characteristics for each of the events, followed by the discharge characteristics and the water quality parameter levels. The values given in the table are event mean concentrations (EMCs). Further discussion of the event data will be deferred to Section 6.

SNOWMELT

During February and March 1982 the snow which had accumulated on the study area over the winter melted entirely, almost continuously. The snow depth measured at the Urbana Morrow Plots weather station reached its maximum of 19 inches for the month on February 9. Melting began on February 11 and continued fairly steadily for 12 days, after which there was no measurable snow left at the station. Only a 2.0-inch snowfall on February 18 interrupted the continuous reduction of the snowpack. Outside the urban area, slower melting of varying depths of snow caused prolonged high flows in the receiving stream.

From February 12 to March 5 the telemetry network was used to collect stream stage data from the sampling sites at one-hour intervals. For two shorter periods during that time span, the automatic samplers were activated to collect discrete samples at self-timed one-hour intervals, with selected samples going to the laboratory for constituent analyses. The data from the sampled periods were treated like storm event data, with the only difference being the time interval between observations. Peak flows, average flows, and flow volumes were calculated from the hydrologic record of each functioning site and used in the determination of average concentrations and washoff loads of water quality constituents. Extrapolations were made from the sampled to the unsampled snowmelt periods to make possible the estimation of the total snowmelt washoff load and its eventual comparison to the total washoff load produced by storm events.

The periods during which runoff quality was monitored were February 15-17 and 20-24. Though melting due to solar radiation began on the 12th and the daily high temperature first exceeded 32°F on the 14th, no appreciable change in streamflow was observed until the 15th. The last water quality samples selected for analysis from the first period were collected late in the evening of the 17th. The next two days were cloudy and cold with 2.0 inches of snow on the 18th, so melting was suspended. However, from the 20th through the rest of the month, daily temperatures exceeded 40°F, and by the 23rd there was only a trace of snow cover left at the Morrow Plots weather station.

During both periods of sampling the urban area and Boneyard Creek behaved in classical fashion, with flow rising gradually each morning to a peak in early afternoon and dropping back to low levels by evening. As expected, the flow behavior was different for the Saline Branch upstream. For the first sampling period the flow increased steadily from the start of monitoring, finally peaking and beginning to decline in the evening of the 17th. In the second period the timing of the cycle in the Saline was different than that of the Boneyard; low flow was observed in the receiving stream around mid-morning and peak flow in the evening.

Daily peaks on the Saline at site 1 during the second period reached values greater than 1500 cfs on three successive days. Because of the large amount of snow, the rapid melting, the efficiency of field drainage, and the lack of opportunity for deep percolation of meltwater, the hydrologic effect of snowmelt from the upstream area far exceeded that of the urban runoff.

For seven constituents, including six with general use water quality standards, the EMCs and ranges observed at each site during the monitored snowmelt periods are given in table 5.3. For lead, copper, and chloride, the highest concentrations and the greatest likelihood of standards exceedances were associated with urban runoff at sites 2, 3, and 4. The iron standard was exceeded everywhere, but concentrations were especially high in the receiving stream. TSS levels were also highest at sites 1 and 5. Phosphorus concentrations were high at all sites, but particularly so at site 5. The behavior of NH_3-N was similar to that of phosphorus though the standard was exceeded only at site 5.

Table 5.4 shows the runoff volumes and washoff loads of the same seven constituents calculated for the two sampling periods at sites 1, 3, and 5. It also shows the extrapolations from the observed records to the entire snowmelt period which were done as part of the calculation of annual loads. These results indicate that the only pollutant loads in the receiving stream which had predominantly urban sources were lead and chloride. The values shown for lead loads at site 1 and 5 are doubtful because all but one of the samples from these sites analyzed for lead had concentrations below detection limits, so estimates of actual levels were used in load

Table 5.3. Snowmelt Constituent EMCs and Ranges

Site		TSS	Cl	NH3-N	P	Pb	Cu	Fe
	Standard (mg/1)	none	500	1.5	0.05	0.1	0.02	1.0
1								
	EMC1	322	17	0.63	0.39	<.05	0.007	4.2
	EMC2	641	9	0.25	0.67	<.05	0.011	8.2
	MAX	1156	28	0.64	0.88	<.05	0.015	13.0
	MIN	14	6	<.10	0.07	-	<.005	0.4
2								
	EMC1	67	245	0.26	0.38	0.30	0.033	3.2
	EMC2	53	68	0.19	0.27	0.10	0.010	1.3
	MAX	310	803	0.60	0.59	0.66	0.100	6.7
	MIN	1	49	<.10	0.11	<.05	<.005	0.1
3								
	EMC1	125	217	0.42	0.42	0.26	0.032	3.0
	EMC2	60	57	0.27	0.36	0.09	0.012	1.4
	MAX	395	728	0.83	0.89	0.53	0.064	6.1
	MIN	2	47	<.10	0.10	<.05	<.005	0.2
4								
	EMC1	227	124	0.26	0.43	0.20	0.029	3.5
	EMC2	-	-	-	-	-	-	-
	MAX	400	498	0.68	1.20	0.25	0.037	4.1
	MIN	29	43	<.10	0.38	<.05	0.006	3.0
5								
	EMC1	314	86	1.31	1.09	<.05	0.015	3.7
	EMC2	635	17	0.58	0.81	<.05	0.014	6.4
	MAX	1042	296	3.90	1.90	0.10	0.047	13.0
	MIN	14	12	0.41	0.58	<.05	<.005	0.2

EMC1 = event mean concentration for 2/15-17 snowmelt
EMC2 = event mean concentration for 2/20-24 snowmelt
MAX = maximum observed concentration of all samples
MIN = minimum observed concentration of all samples

Table 5.4. Snowmelt Constituent Loads
(units are 1000 kg except as noted)

Date	Site	Flow volume (10^6 ft^3)	TSS	Cl	NH3-N	P	Pb (kg)	Cu (kg)	Fe
2/15-17									
	1	63	612	29	1.2	.7	18	12	7.7
	3	15	54	94	.2	.2	113	14	1.3
	5	80	711	196	3.0	2.5	45	34	9.5
2/20-24									
	1	335	6140	87	2.4	6.4	96	105	79.0
	3	20	35	33	.2	.2	42	7	.8
	5	380	6880	160	3.8	7.4	131	129	88.5
2/12-3/5									
	1	585	8600	150	4.7	9.1	146	150	110
	3	100	180	265	.7	.8	340	43	4
	5	700	9000	535	12.0	14.0	320	230	125

calculation. Comparisons of upstream to downstream loads of TSS, iron and copper show that the greatest part of their loads were produced by runoff from the agricultural area. Phosphorus and NH3-N seem to have significant sources upstream too, but major amounts, especially of NH3-N, were introduced downstream from site 3, possibly by the sewage treatment plant effluent. The part snowmelt plays in annual loadings will be discussed later.

RAINFALL QUALITY

Wet fallout samples were collected from May through September, 1982, in an effort to determine the atmospheric contribution to washoff quality in the streams. Of the twelve samples collected during this period, six were determined to be potentially contaminated either by dry weather fallout collected due to equipment failure or because more than one short duration, low intensity event occurred between sample collections. Such samples can have inordinately high concentrations of some contaminants, leading to the potential overestimation of the atmospheric contribution to stream water quality with respect to these contaminants.

Of the six samples that were analyzed, only four parameters had enough non-trace values to allow characterization of the wet fallout for the period. Table 5.5 shows the results of this sampling.

Table 5.5. Wet Deposition Quality Summary

Parameter	MIN	MAX	MEAN	(units)
NH3-N	.12	.42	.30	(mg/1)
N03-N	.16	.62	.40	(mg/1)
Specific Conductance	10.	40.	22.	(µ-mhos/cm)
pH	3.4	7.8	5.0	

Comparison of these data against the event mean concentrations of the concurrent event data shows that NH3-N and N03-N are supplied significantly by the atmosphere.

Recent work at the Illinois State Water Survey[8] has been involved with the temporal variations of rainfall quality during an event. These results have shown that for the constituents investigated (N03-N, sulfate, calcium and magnesium), the starting concentrations are relatively high, and that these concentrations vary inversely with rainfall intensity over time. In other words, as rainfall intensity increases, the concentrations of these constituents in the rainfall decreases, to levels as low as ten percent of their initial concentrations. As rainfall intensity diminishes toward the end of a storm the concentrations rise to levels approximating their starting values. These same data also indicate that pH varies directly with rainfall intensity.

Due to the size and time of concentration of the Boneyard Creek basin, there may be some discrepancies in the analysis of the atmospheric contribution to runoff quality. The minimum stream depth for runoff sampling at a site may occur after the runoff from the initial high-concentration rainfall has passed the site, and sampling may end before the later rain, also of relatively high concentration, has a chance to run off. The early rain is also more prone to abstraction from the effective precipitation by dry pavement, depression storage, and initial infiltration. For these reasons the event mean concentrations of some constituents in runoff may be less than the concentrations of the same substances in wet fallout samples for an event.

A check of sample data shows that the wet deposition sample concentrations are generally less than the constituent mean concentrations in the runoff samples, except for NH3-N, which is less only at site 5, downstream from the sewage treatment plant. The wet fallout samples also confirm the rainfall acidity levels identified previously in the NURP reports, with an average pH range from 3.0 to 5.0 from May through August, and an average value greater than 5.0 from September through April.

SEDIMENT OXYGEN DEMAND

The SOD test chamber is a rectangular steel box with one open side panel. The chamber is placed open side down on the bottom of a stream or lake to enclose a specific area of bottom material and to confine a specific volume of water. The chamber used by ISWS has a volume of 7.7 liters and an enclosure area of 0.0542 square meter. The chamber is fitted with a dissolved oxygen (D.O.) probe connected to a meter which is kept on the stream bank. During a test the chamber is placed on the stream bottom and the D.O. within is monitored for 90-120 minutes as it is gradually consumed. A plot of oxygen consumed against time elapsed is used to calculate the SOD graphically. Water temperature measurements are also made so that observed values can be adjusted to a standard value corresponding to a water temperature of 20°C.

Figure 5.1 is a sample plot of the results of an SOD monitoring run. The straight-line portion of the curve between 30 and 90 minutes was used to calculate the steady D.O. consumption rate S of 0.0232 mg/1 per minute. To convert this rate into SOD, which is conventionally expressed in units of g/m /day, the following equation is used:

$$SOD = 1.44\ (SV/A)$$

V = volume of chamber, in liters

A = area of bottom covered, in square meters

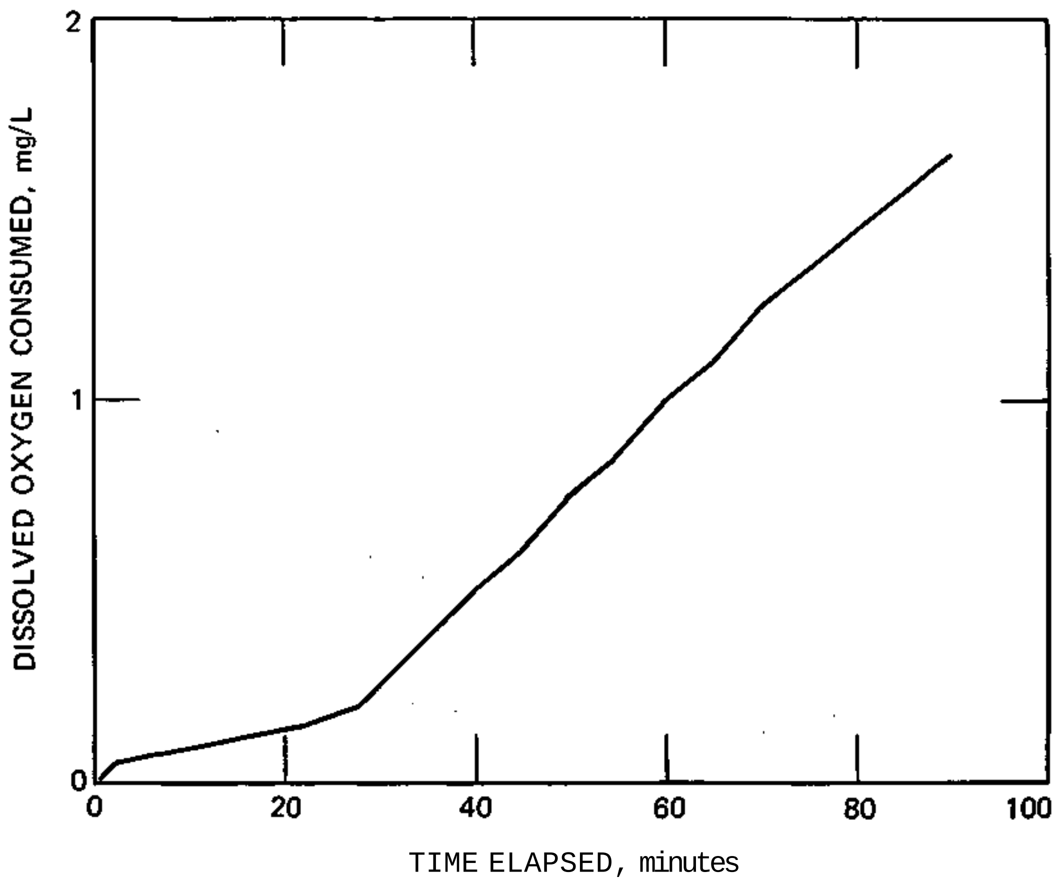


Figure 5.1. Sample plot of SOD test result

For the test chamber used by ISWS

$$SOD = (205.5)S$$

For example, then, SOD = 4.77 $g/m^2/day$. The water temperature during this test was 25°C. The relationship involving temperature is as follows:

$$SOD_T = SOD_{20} \ (1.047_{T-20})$$

SOD_T = sediment oxygen demand at test temperature

SOD_{20} = sediment oxygen demand at 20°C

T = test temperature, in °C

The use of this expression produces an SOD_{20} = 3.79 $g/m^2/day$ from the data collected during this test.

As mentioned in the methodology section, there were 14 SOD tests run on the Saline Branch: three each at sites 1, 4, and 5; one each upstream from site 1, between sites 1 and 4 and between sites 4 and 5; and two downstream from site 5. The results of the tests, ordered from upstream to downstream, are shown in table 5.6. The values reported for sites at or downstream from the sewage treatment plant outfall are much higher than for sites further upstream, including those near site 4 where influence of Boneyard Creek should be evident. This suggests an impact of the treatment plant on the receiving stream sediments. However, examination of the test plots reveals that those indicating high oxygen consumption also show a pattern that is characteristic of demand exerted by algal respiration. This pattern is shown in figure 5.1; as the algae which had been photosynthesizing were enclosed in darkness, there was a period of no change in the chamber D.O., before respiration of oxygen began. Such a demand is not a "true" SOD, then, because it is not constantly exerted. Instead it is part of the diurnal D.O. cycle in the stream; the algae

Table 5.6. SOD Test Results

Test number	Location	SOD_{20}
1	2 miles upstream from site 1	1.90
2	Site 1 - 100 ft upstream from bridge	1.49
3	Site 1 - at bridge	0.85
4	Site 1 - 500 ft downstream from bridge	0.66
5	1.5 miles upstream from site 4	0.42
6	Site 4 - 100 ft upstream from weir	1.34
7	Site 4 - at weir	0.90
8	Site 4 - 100 ft upstream from STP outfall	2.16
9	1.5 miles upstream from site 5	2.35
10	Site 5 - 200 ft upstream from bridge	9.48
11	Site 5 - 100 ft upstream from bridge	5.60
12	Site 5 - 300 ft downstream from bridge	2.27
13	1 mile downstream from site 5	3.79
14	4 miles downstream from site 5	7.13

consume oxygen during hours of darkness but produce it in hours of sunlight.

In light of this interpretation of the evidence, reconsideration of the test data and examination of samples of bottom material collected at each test site led to an estimate of the continuous SOD of 0.5-1.0 $g/m^2/day$. Values in this range are characteristic of streams with clean bottoms and no D.O. problems related to benthic bacteria demands. There could still be a D.O. problem associated with algae in the stream, however. The behavior of algae would be influenced by seasonal shifts, as well as daily variations, in streamflow and available nutrients and light. The treatment plant effluent could figure strongly in such a problem because of both the nutrient supply and the flushing effect on the stream provided by the effluent.

RECEIVING STREAM SEDIMENT

A limited program of sampling stream bottom materials was carried out in the Saline Branch. Six samples, three each at sites 1 and 5, were collected for determination of particle size distribution. The samples came from midstream and points near both banks of a cross section 100 feet upstream from the water quality sampling station at site 1. The same kind of sampling was done at a cross section 200 feet upstream from site 5. An Ekman dredge was used to collect the bottom material. In the laboratory each sample was washed through a set of sieves with the following mesh sizes: 2000µ, 1000µ, 500µ, 250µ, 125µ, 63µ, and pan. The sample fractions retained on the sieves and passing the finest mesh were kept separate for drying and weighing.

Table 5.7 contains the total weights of the six samples and the weights and fractions of the totals in each particle size group. Figure 5.2 has bar diagrams for both sites representing the averages of the fractions of the totals in each particle size groups for the three samples. It is clear that the particle size distributions of the bottom materials at the sites are quite different. The median particle size of the average of sample for site 1 is 335μ, while for site 5 it is 2300μ. The proportion by weight of fines is much lower at site 5 than at site 1. This suggests that, for the most part, urban runoff solids and other fines do not accumulate in the downstream reaches of the Saline within the study area, but instead are flushed through the system and scoured from the stream bed to be deposited somewhere downstream. The washout of fine sediments from the downstream reach is probably due mainly to the effects of the surge of urban runoff entering the receiving stream. The increased dry weather flow, due to additional baseflow and to the sewage treatment plant effluent, and the changed stream geometry downstream might also contribute to the differences in sediment characteristics. It should also be noted that the sediment samples analyzed were collected in October and that a year-round sampling program might reveal some seasonal or annual pattern of deposition and scour.

Sediment samples for constituent analyses were also collected in October at sites 1 and 5 and at a point 2.2 miles downstream from site 5. The current IEPA sediment sampling procedure[5] was followed to collect only material smaller than 63μ at each site and preserve it for analysis. The results of analysis of these samples are shown in table 5.8. Except for volatile solids, reported in percentage of total solids, the values are given in units of mg constituent per kg dry solids.

Table 5.7. Particle Size Distribution of Stream Bottom Samples

			WEIGHT/FRACTION OF TOTAL SAMPLE IN PARTICLE SIZE GROUP						
Site	Location	Sample weight (grams)	>2000μ	2000-l000μ	1000-500μ	500-250μ	250-125μ	125-63μ	<63μ
1	Near north bank	1295.9	291.7	185.9	194.3	312.1	80.6	26.0	205.3
			.23	.14	.15	.24	.06	.02	.16
	Midstream	1462.9	0.1	145.5	239.6	767.2	208.3	15.4	86.8
			.00	.10	.16	.53	.14	.01	.06
	Near south bank	314.7	11.2	8.1	16.1	74.4	106.5	36.4	62.0
			.04	.03	.05	.24	.34	.12	.20
5	Near north bank	375.3	43.3	53.3	103.3	119.2	47.1	4.6	4.5
			.12	.14	.28	.32	.13	.01	.01
	Midstream	703.2	529.8	42.3	44.1	63.8	15.7	1.7	5.8
			.75	.06	.06	.07	.02	.002	.01
	Near south bank	821.9	570.6	129.8	66.9	30.9	12.4	3.5	7.8
			.69	.16	.08	.04	.02	.004	.01

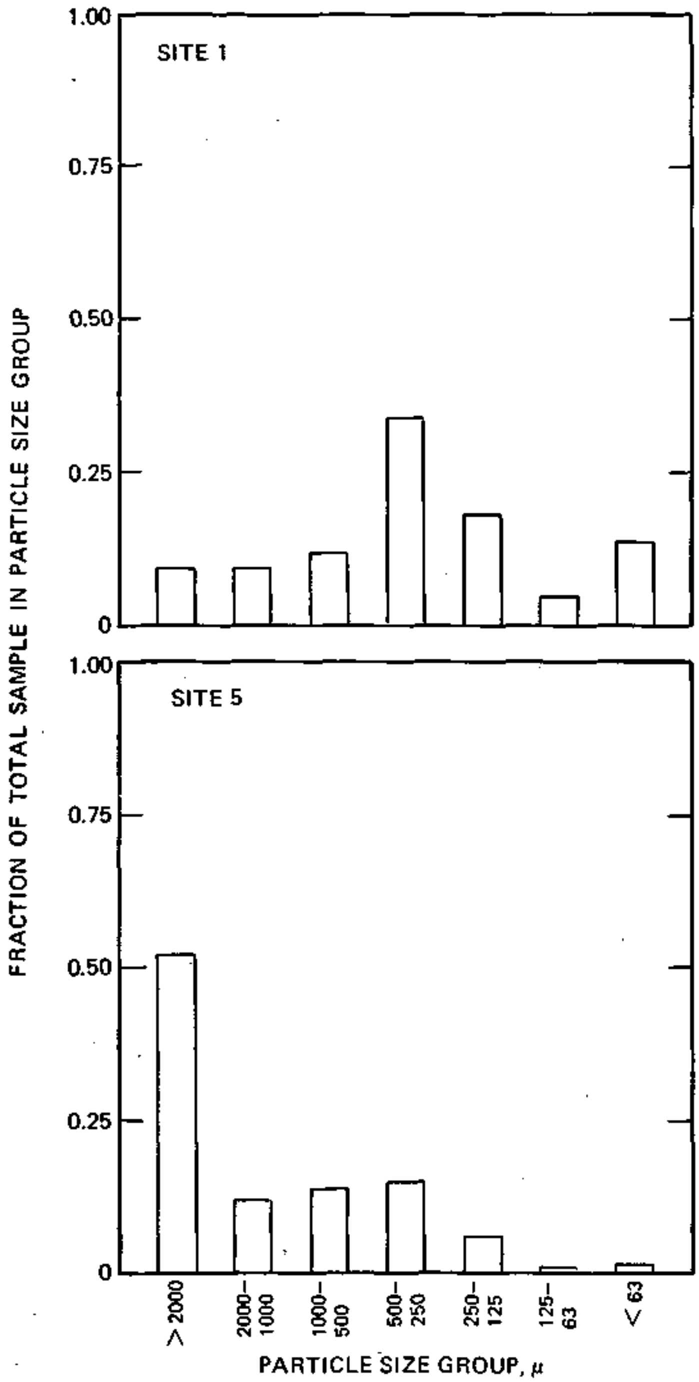


Figure 5.2. Average particle size distributions of bottom material at sites 1 and 5

Table 5.8. Sediment Sampling Results — 1982

Constituent	Site 1	Site 5	Below Site 5
Volatile Solids (%)	8.1	7.8	8.3
TKN	2410	3320	4580
Phosphorus	423	1580	1990
COD	56900	111000	109000
Lead	26	230	180
Copper	20	66	59
Iron	21000	23000	22000
Zinc	90	240	210
Chromium	17	90	79
Cadmium	<1.0	2.0	2.0
Manganese	900	970	930
Arsenic	5.2	6.1	5.2
Mercury	0.03	0.29	0.28

All values in mg/kg dry solids, except Volatile Solids in percent by weight

The relative impacts of urban runoff loads on the receiving stream sediments may be assessed by making comparisons of the values observed upstream of the cities (site 1) to those seen downstream (site 5 and beyond). The 13 constituents may be divided into three categories: unchanged from upstream to downstream, increases of two to five times and increases of ten or more times. Constituents in the first category include volatile solids, iron, manganese, and arsenic. Those in the second category, demonstrating moderate increases, are TKN, phosphorus, COD, zinc, and chromium. Those in the final category, showing large increases, are lead, copper, cadmium, and mercury.

The constituents showing the greatest downstream increases are identifiable as urban runoff pollutants, especially lead and copper. The sewage treatment plant effluent is a source of soluble TKN, phosphorus, and COD which could be incorporated into the sediments downstream. However there is almost no lead, copper, mercury, zinc, chromium, or cadmium in the plant effluent, so the only source for these materials in downstream sediments must be urban runoff. Stormwater samples from this study were not analyzed for mercury or zinc. The sediment particle size distribution data indicate that fines are scarce downstream, but the quality data show that the fines which do exist are high in metals of probable urban origin. An additional finding of interest is the lack of difference between upstream and downstream concentrations of iron and manganese. This suggests that these pollutants are essentially geologic in character, and that they occur in runoff because of high solids concentrations and not because of any particular urban source.

SEWAGE TREATMENT PLANT

The Urbana-Champaign Sanitary District keeps daily records of the average effluent loadings to the Saline Branch. These loading rates are in terms of daily mean discharge rate and flow-weighted composite samples for LoLal suspended solids, total NH3-N and the five-day biochemical oxygen demand (B0D5). Inspection of the data collected for sites 4 and 5, upstream and downstream of the treatment plant outfall, respectively, indicates that there are substantial increases in six parameters in this reach. These six parameters are NH3-N, N03-N, TKN, phosphorus, chloride, and sulfate, and all of these constituents are generally found in significant quantities in sewage treatment plant effluent.

Because NH3-N is the only one of these six parameters that is measured on a regular basis, the records were analyzed to determine whether or not the increase in NH3-N loading between sites 4 and 5 could be attributed to the sanitary plant outfall. Interpolation of the outfall recorder charts to hourly values for selected event days showed that the plant effluent discharge rate may vary by as much as 100 percent with respect to the average rate for the day. Using these discharge data with the daily average concentrations, and removing the resultant load from the site 5 data showed that the increase in NH3-N at site 5 was due to the treatment plant effluent.

The following table shows the monthly average data reported by the Sanitary District for the northeast plant effluent during the study period:

Month, Year	Discharge (cfs)	TSS (mg/1)	B0D5 (mg/1)	NH3-N (mg/1)
Oct, 1981	20.8	22	27	10.4
Nov, 1981	17.2	29	43	11.4
Mar, 1982	33.8	16	14	9.2
Apr, 1982	25.1	12	17	11.2
May, 1982	22.0	15	22	9.6
Jun, 1982	18.8	10	24	7.1
Jul, 1982	20.5	10	18	4.0
Aug, 1982	16.1	8	21	5.5
Sep, 1982	17.0	4	29	5.9

As can be seen from the above table, the total suspended solids concentration in the effluent was maintained at a level below the permit constraint of 30 mg/1 for average concentration. The five day biochemical oxygen demand exceeded the permit average concentration of 25 mg/1 in three months, but only in November did the concentration also exceed the maximum level of 38 mg/1. The permit also mentions an average flow of 24.8 cfs. This level was exceeded only during March and April.

ANNUAL LOADS

In addition to the analysis of dry weather flow and event data, it was considered desirable to estimate the annual loads to the receiving water. This provides a means for relating the effects of dry weather flow, storm events, and snowmelt. The observed data in this project comprised hydrologic records for 31 storm events, 22 days of snowmelt runoff, and numerous periods of dry weather. Water quality records were available for 28 of the events, 8 days of snowmelt, 13 days of dry weather, and rainfall quality for 6 events. In addition, daily measurements of precipitation and of sewage treatment plant effluent quantity and quality were available for the period of the study. For three constituents, TSS, NH3-N, and lead, estimates were made of the total loads passing sites 1, 3, and 5 during the period of data collection, October 1981 - September 1982. The loads from unsampled storm events were estimated using the daily precipitation record and the runoff-load relationships developed in the characterization of urban runoff. The loads for dry weather periods were calculated from USGS and ISWS flow records and representative concentrations of dry weather flow samples collected at each site during the project. Snowmelt loads were estimated by extrapolating from the two periods of runoff sample collection and analysis to the entire 22-day period of meltwater runoff during which flow data were collected. Loads at site 1 were then increased by a factor of 1.25 to represent all of the rural area and loads at site 3 were increased by a factor of 2.17 to represent all of the urban area.

The results of these estimations appear in table 5.9. It is interesting to note that although snowmelt accounted for 64 percent of the annual TSS load, it carried only 34 percent of the lead and 5 percent of the NH3-N. Storm runoff, on the other hand, accounted for 28 percent of

Table 5.9. Estimated Annual Loads

$TSS = 14,050 \times 10^3$ Kg

	Storm runoff	Snowmelt	DWF	STP
Urban Area	3300	550	80	
Rural Area	700	8450	720	
SUB TOTAL	4000	9000	800	250

NH3-N = 157,350 Kg

	Storm runoff	Snowmelt	DWF	STP
Urban Area	1200	1800	3500	
Rural Area	150	6200	1500	
SUB TOTAL	1350	8000	5000	143,000

Lead = 2750 Kg

	Storm runoff	Snowmelt	DWF	STP
Urban Area	1800	800	T	
Rural Area	T	150	T	
SUB TOTAL	1800	950	T	T

T = trace

the annual TSS load but carried 65 percent of the lead and 1 percent of the NH3-N. The sewage treatment plant outfall produced an estimated 91 percent of the NH3-N. Again, this was prior to recent improvements that have greatly increased NH3-N removal.

Although the urban area amounts to only 14.3 percent of the total watershed area, it produced 28 percent of the TSS load and carried nearly 95 percent of the lead load. Of this urban lead load, about 69 percent occurred during storm runoff periods.

SECTION 6

ANALYSIS OF STORM DATA

In this section, EMCs and total loads of selected pollutants will be compared at upstream and downstream sites using all available storm data. EMCs were calculated as previously described for each constituent at each site for all events with reliable data. Constituent loads were calculated by multiplying EMCs by the event runoff volumes. All of these data are presented in Appendix I tables I.1 and I.2.

EMC COMPARISONS

Figure 6.1 is a set of six plots, one each for the constituents TSS, TDS, NH3-N, phosphorus, lead, and iron. The points plotted represent EMCs of the appropriate constituent for site 1 and EMCs of the same constituent for the same events at site 3. The general use water quality standards for lead, iron, and NH3-N are shown on the plots. The NH3-N standard shown plot is the one in effect at the time the data were being collected; it has since been revised upwards, as discussed earlier. Figures **6.2-6.5** contain similar plots from other site pairings: 1 and 4, 1 and 5, 3 and 5, **and** 4 and 5 respectively.

Only occasionally during the monitoring period was there any significant runoff at site 1 as a result of storm rainfall in the urban area. This was the result of the typically small areal coverage of thunderstorms and of the low runoff coefficient in the agricultural basin. The upstream flow in the Saline was usually low and nearly constant throughout an event. The exception to this occurred early in the spring when snowmelt, field tile drainage, and groundwater contributions raised the flow in the Saline to eight times its midsummer discharge. When this

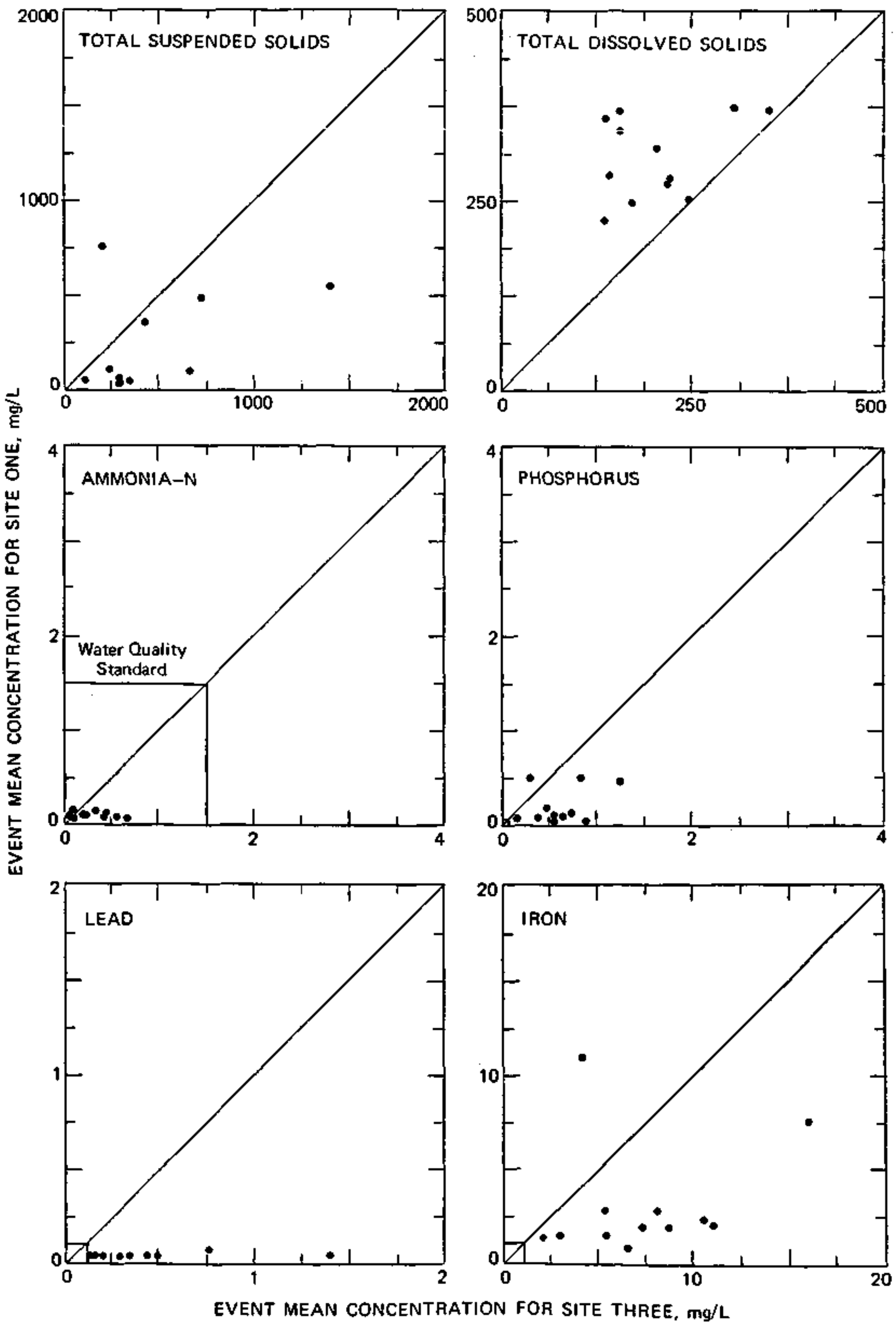


Figure 6.1. Event mean concentrations - site 1 vs. site 3

happened the concentrations of solids and constituents associated with solids were also high. There are a few points on the TSS, iron, and phosphorus plots where the site 1 EMC is higher than that from site 3. These points correspond to events in the early spring when the receiving stream flows and constituent levels were larger than those of urban runoff from small storms.

Figure 6.1 compares the upstream agricultural flow with that of the urban discharge (site 3). Some trends are clear from these plots. For the constituents shown, only TDS occurs in higher concentration at site 1. Concentrations of the other constituents are substantially higher in the urban runoff and always exceed the water quality standards for lead and iron. It should be noted, however, that iron also tends to exceed the standard in the agricultural runoff.

Figure 6.2 compares EMCs from site 1 to those from site 4. The principal difference between these two sites on the Saline is that flow at site 4 includes the contribution of the Boneyard. As they should, these plots look essentially like those in figure 6.1. Site 4 represents the urban flow at site 3, with a little more contribution from ungaged urban area, diluted by the receiving stream flow. The plots show the effects of the dilution as the clusters of points on the TDS plot shifts slightly to the right and on the other plots to the left.

Figure 6.3 compares the EMCs for site 1 with those of site 5. The difference between these two sites on the receiving stream are greater than for sites 1 and 4. Site 5 represents the urban flow passing through site 4 plus the considerable contribution of the sewage treatment plant effluent. Other small unidentified sources may also affect the stream between sites 4 and 5. The differences between figures 6.2 and 6.3 are generally

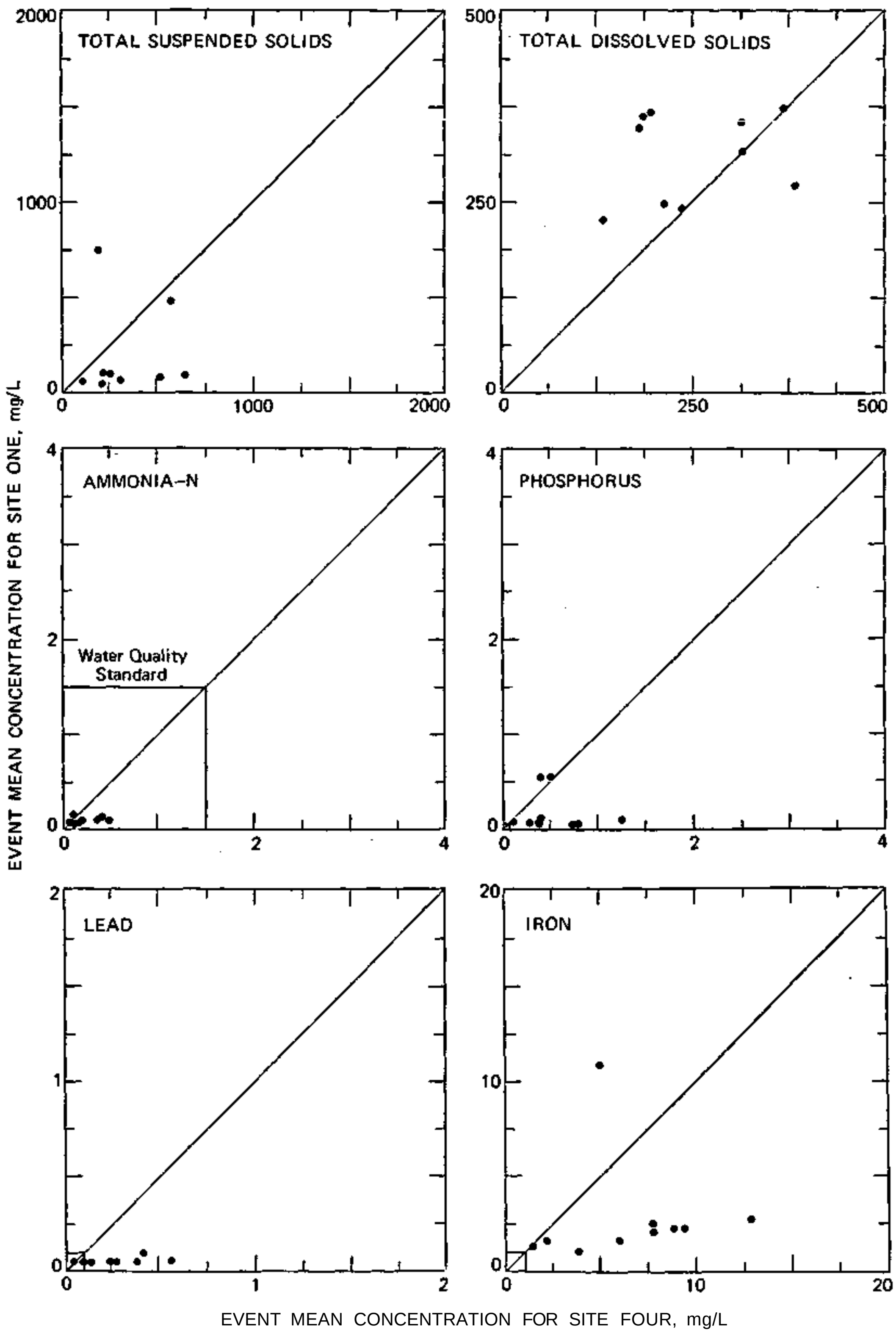


Figure 6.2. Event mean concentrations - site 1 vs. site 4

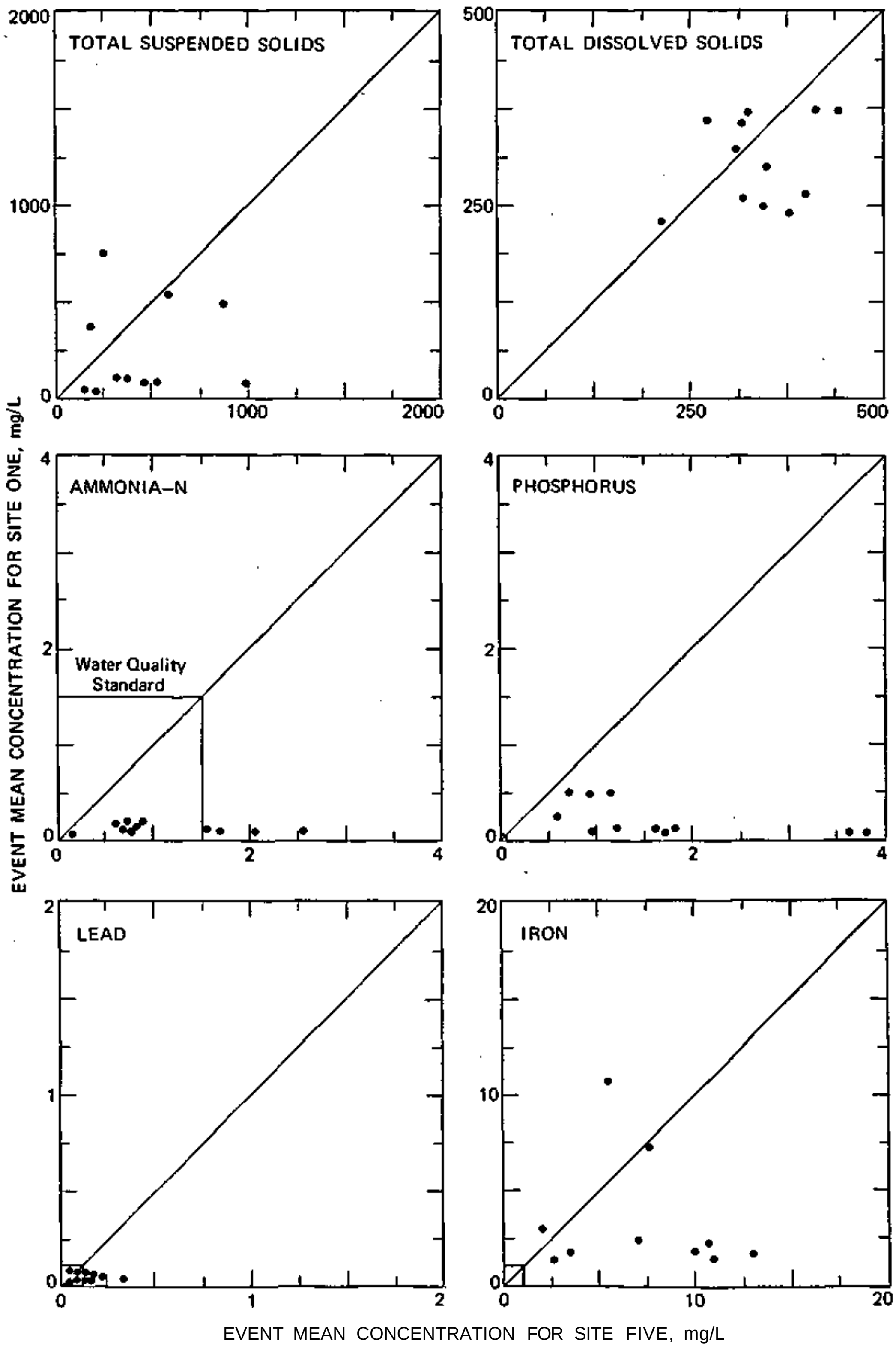


Figure 6.3. Event mean concentrations - site 1 vs. site 5

attributable to the sewage treatment plant effluent. The shift of points to the right indicates substantial increases in NH3-N and phosphorus as expected. The shift to the left in lead indicates a dilution effect from the sewage treatment plant effluent.

Figure 6.4 features EMCs for sites 3 and 5. Again, site 5 represents the urban runoff at site 3 plus receiving stream dilution, sewage treatment plant contribution, and the effects of a 90-120 minute difference in peak times. The attenuation of the flow peak and the prolongation of the event suggest the possibility of deposition of runoff solids between the sites. The lead plot shows lower values at site 5, which fits the idea of deposition in the downstream reach. However, TSS values are greater downstream, implying other sources or resuspension and scour in the same reach. While the similar increases of TDS, NH3-N, and phosphorus downstream are attributable to the treatment plant effluent, the TSS increase is not. The results for iron do not clarify the situation, for it appears to be acting as an urban pollutant like lead part of the time, and as a constituent associated with solids, regardless of origin, the rest of the t ime.

Figure 6.5 compares EMCs for sites 4 and 5. Again, because of the similarity of flows at sites 3 and 4, these plots look much like those in figure 6.4. The levels of lead at site 5 are lower while those of TDS, NH3-N, and phosphorus are distinctly higher. The clusters of points in the TSS plot are shifted to the right from those in figure 6.4, making the trend toward higher values downstream clearer. The comparison of iron EMCs also follows the solids trend better in figure 6.5 than in figure 6.4.

Consideration of each constitutent serially through the five figures adds to the understanding of the system. For TSS, the EMCs at site 1 are

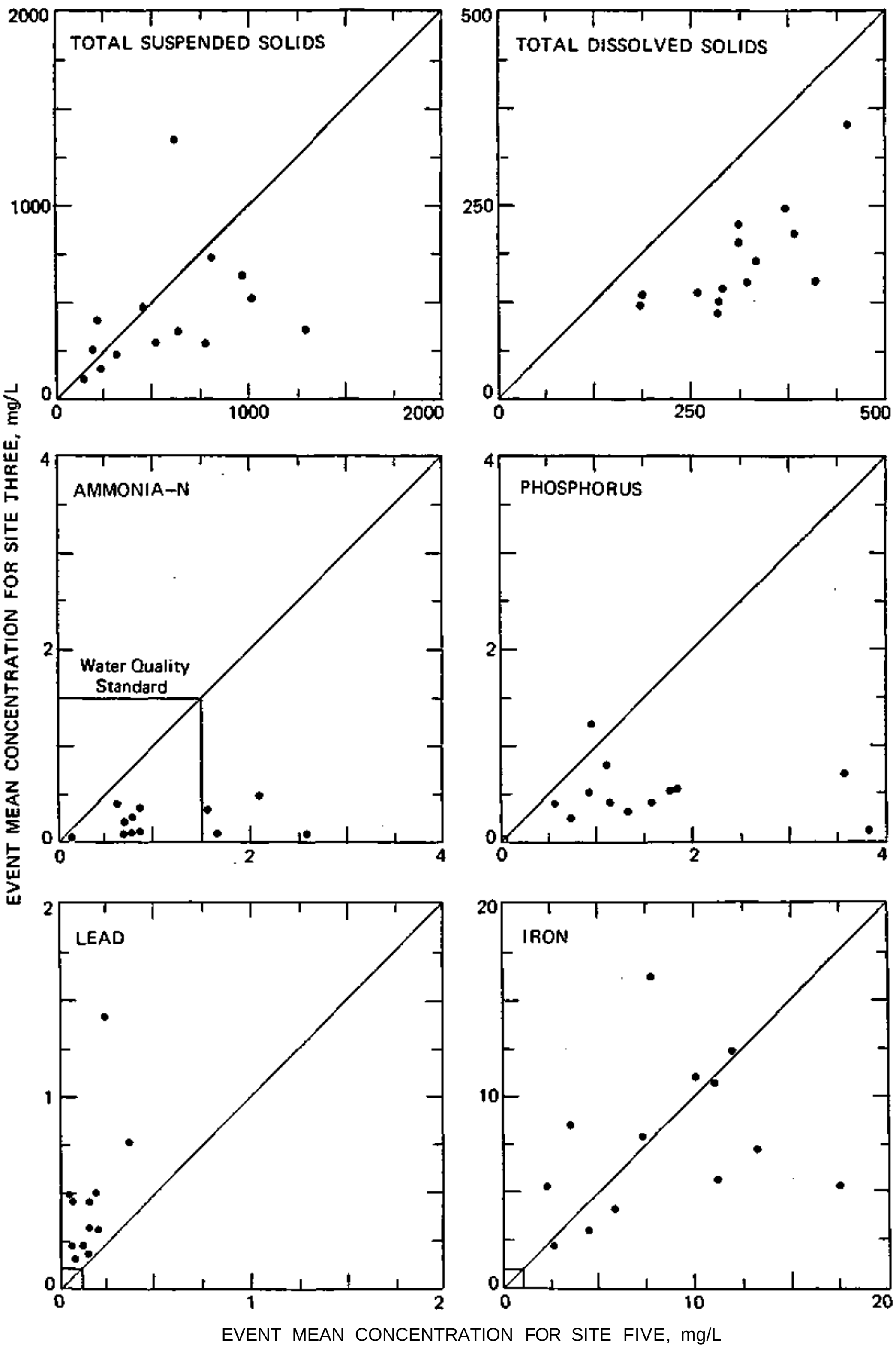


Figure 6.4. Event mean concentrations - site 3 vs. site 5

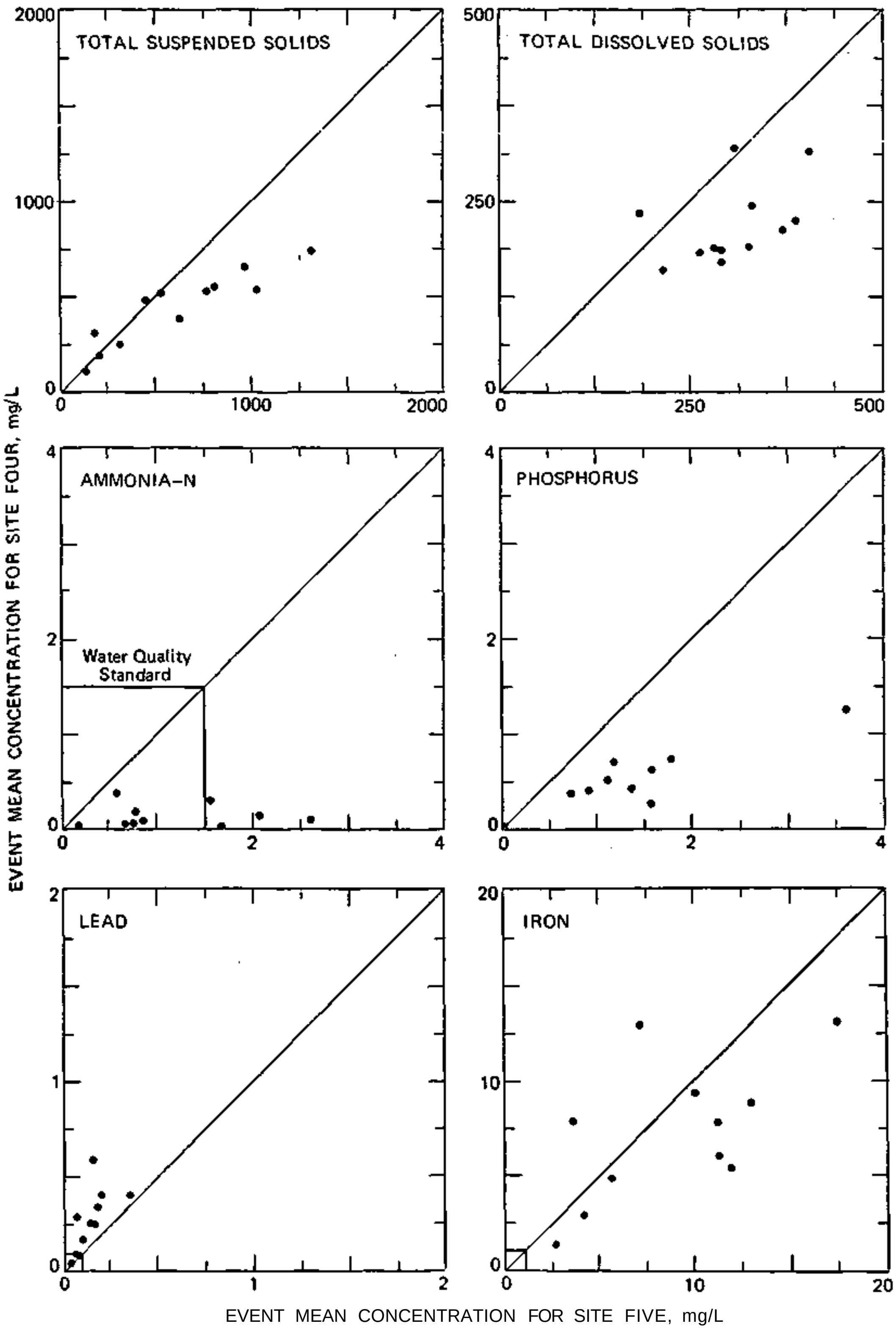


Figure 6.5. Event mean concentrations - site 4 vs. site 5

less than those at sites 3, 4, and 5, and those at both sites 3 and 4 are less than those at site 5. The high concentrations of solids in urban runoff are only marginally affected by receiving stream dilution so that the TSS level in the Saline is still high prior to inflow from the treatment plant. The increases at site 5 indicate some other source downstream from site 4. This additional source cannot be the treatment plant because the TSS levels in its effluent are insufficient to raise the stream concentration, even in dry weather flow. Since it seems unlikely that deposition of solids, resulting in the observed decline in lead EMCs, and scour and resuspension of solids would occur simultaneously in the same reach, additional undocumented sources between the sewage treatment plant and site 5 appear the most probable reason for the increase in EMCs of TSS at site 5.

The EMCs of TDS at sites 3 and 4 are less than those at sites 1 and 5, which are roughly equal. This shows that the high values in the Saline upstream are diminished by mixing with urban runoff. The return to high levels at site 5 is due to contribution from the treatment plant and possibly from other sources, including dissolution of solids in the stream.

The EMCs of phosphorus and NH3-N show similar patterns: those at site 1 are less than those at sites 3 and 4 which, in turn, are less than those at site 5. This indicates that there are significant amounts of these constituents in urban runoff but that the greater portions of them in the Saline are from the treatment plant effluent.

The EMCs of lead show unique behavior: the levels at sites 3 and 4 are greater than those at sites 1 and 5, and those at site 5 are greater than those at site 1. All of the lead in the streams is of urban origin.

For iron, the EMCs at site 1 are much less than those at sites 3 and 4, which, in turn, are slightly less than those at site 5. Iron generally seems to associate with solids and is not exclusively an urban pollutant, so any high stream flow, in urban runoff or receiving stream, will probably have high solids and high iron concentrations.

The basic operation of the system, in terms of the six chosen constituents, can then be described as follows. The receiving stream usually has low background flow with high TDS concentration and low levels of other constituents. Urban runoff, introduced to the Saline by the Boneyard, has high concentrations of TSS, lead, and iron, moderate concentrations of NH3-N and phosphorus, and low TDS levels. At site 4 on the receiving stream the distribution of EMCs is similar to that for site 3, but the values themselves are slightly lower due to a mild effect of dilution by the receiving stream. At site 5, on the downstream end of the Saline in the study area, TSS is high, apparently due to some unnamed source; iron associates strongly with solids; TDS levels return to normal and NH3-N and phosphorus concentrations are high due to the contribution from the sewage treatment plant; and lead concentrations are lower than those in the urban stream due to deposition in the downstream reach and to dilution. General use water quality standards are regularly exceeded for lead and iron downstream from site 3; the outdated NH3-N standard, recently revised, is also frequently exceeded downstream from site 5; and the phosphorus levels in the Boneyard and Saline would exceed standards for every event.

Other constituents not plotted also showed recognizable behavior patterns. Copper behaves very much like lead, though there is slightly more background copper in dry weather flows. Manganese acts like iron, except that its concentration rarely meets or exceeds standards. . N03-N seems to exist in fairly steady concentrations in rainfall, dry weather flow, urban runoff, and treatment plant effluent. TKN and COD act somewhat like phosphorus: they are not exclusively urban pollutants, they associate partially with solids, and they exist in significant levels in treatment plant effluent. Very little chromium or cadmium appears in urban runoff; most analyses for these substances show levels less than detection limits, so reliable EMCs cannot be calculated for them, but standards are not threatened.

LOAD COMPARISONS

To go beyond concentration comparisons, event washoff loads were organized and plotted in a fashion similar to that just shown for EMCs. The benefit of examining loads is that the differences in hydrologic responses of the sites to a storm event are in effect incorporated into the load calculation, so they do not have to be accounted for separately. Thus the actual progress and fate of given pollutants in the system can be followed better, and sinks or additional sources can be identified. Figures 6.6-6.10 feature event washoff load plots for the same six constituents as the EMC plots, with site vs. site pairings in the same order.

The first and most basic comparison is that of the urban stream to the receiving stream upstream from the urban area. As can be seen in the six plots of figure 6.6, most of the plotted points fall well below the 45° line of equality, meaning that for most events, the agricultural area contribution to the receiving stream for these parameters is negligible when compared with the nonpoint source contributions of the urban area. As noted with the EMC plots, the few high points at site 1 occurred during an event with relatively high flow at site 1.

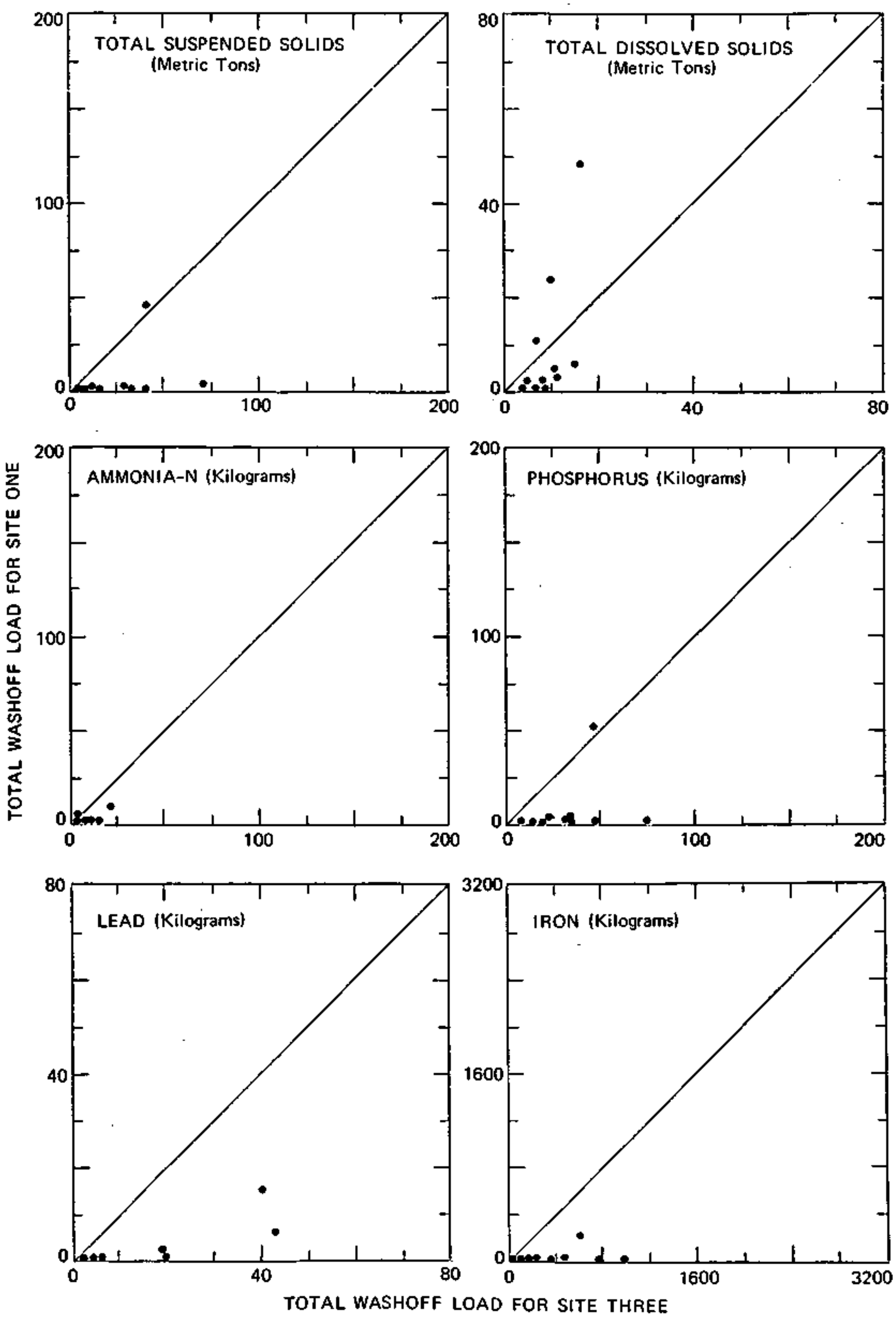


Figure 6.6. Event washoff loads - site 1 vs. site 3

The second comparison is for the upstream receiving stream site against the receiving stream site immediately below the mouth of the urban stream, figure 6.7. The urban loads contributed to site 4 for each of the six parameters significantly overshadow the loads for the non-urban areas upstream. In terms of total loads at site 4, about 87.5 percent of TSS, 64 percent of TDS, 99 percent of NH3-N and phosphorus, 95 percent of lead, and 90 percent of the iron load are from the urban area.

The third comparison is the furthest upstream site on the receiving stream against the furthest downstream site on the receiving stream, figure 6.8. Comparing figures 6.7 and 6.8 it can be concluded that NH3-N and phosphorus loads are increasing between sites 4 and 5. Other results are obscured by the fact that different sets of points were used for the two plots.

The increases in loads of nutrients are most probably due to the sewage treatment plant effluent. This was discussed earlier with respect to NH3-N concentrations.

Figure 6.9, the urban outfall plotted against site 5, and 6.10, site 4 plotted against site 5 show nearly identical results. They show that the load of each of the six constituents except lead increases from a point below the urban discharge to a point several miles below the urban area. The fact that lead load decreases slightly while suspended solids increases is surprising.

In order to address the increase in suspended solids load while the lead is apparently settling out, the difference in the TSS loads between sites 4 and 5 were plotted against dry days, mean discharge, and peak discharge at site 5. These data, shown in figure 6.11, show that there is

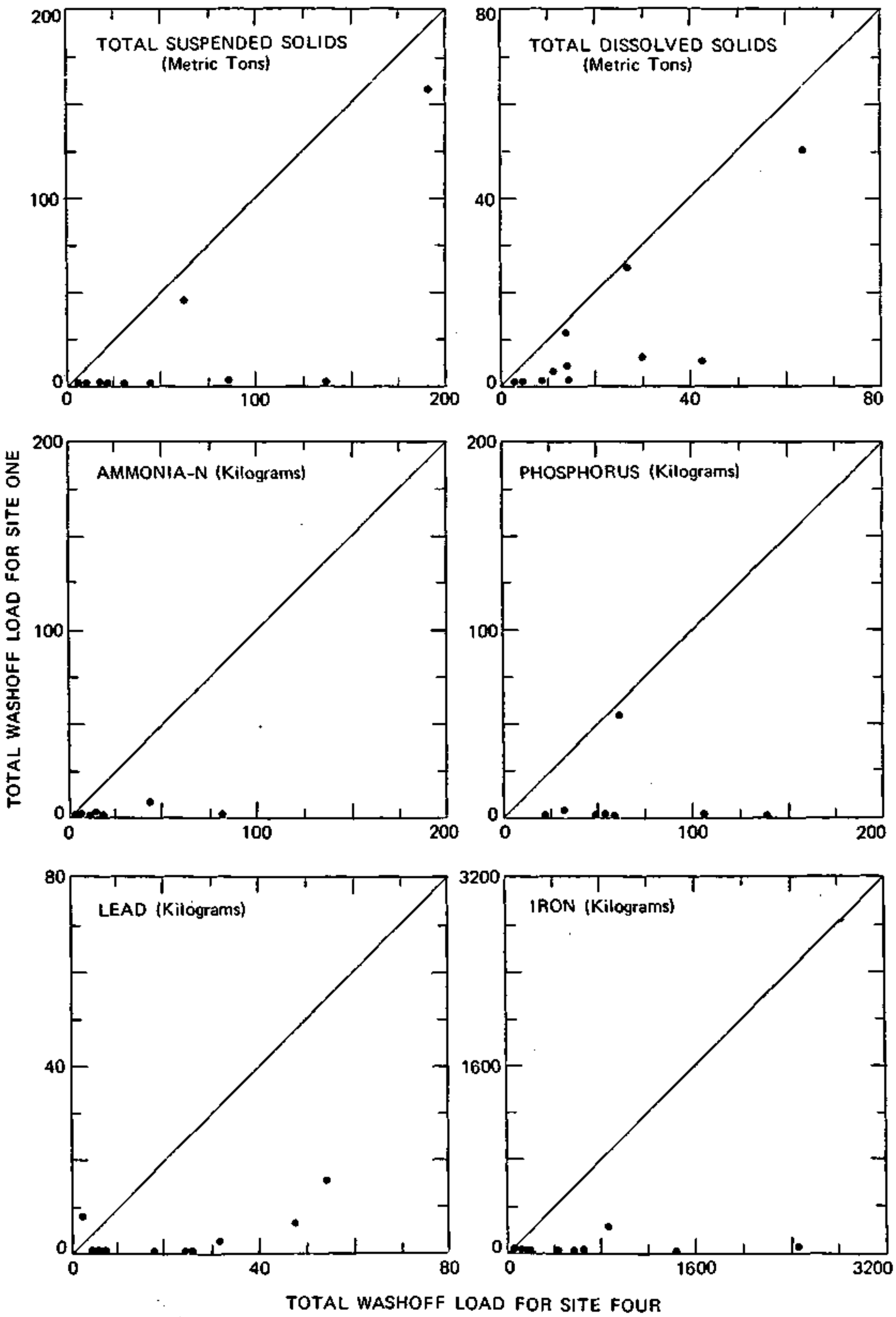


Figure 6.7. Event washoff loads - site 1 vs. site 4

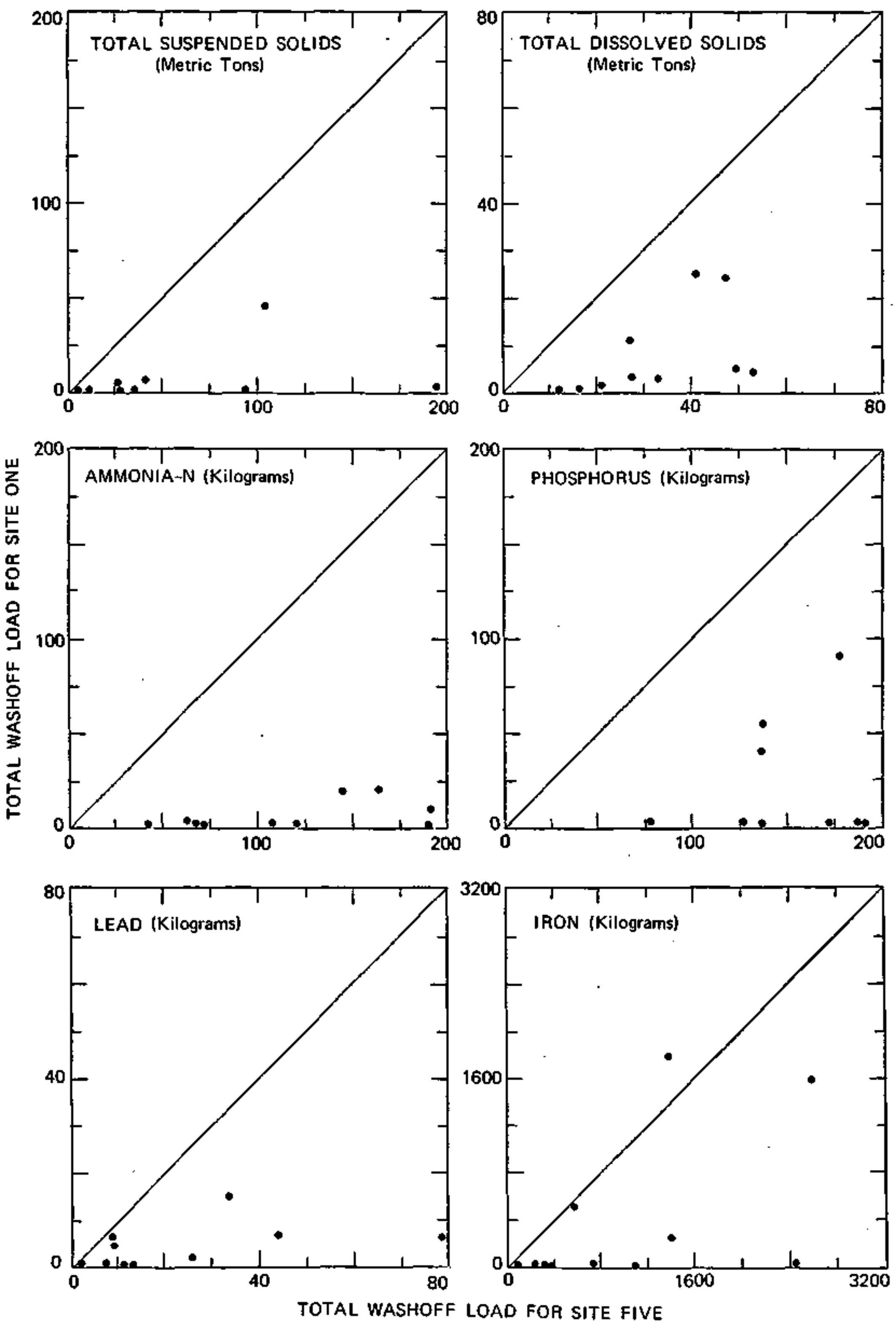


Figure 6.8. Event washoff loads - site 1 vs. site 5

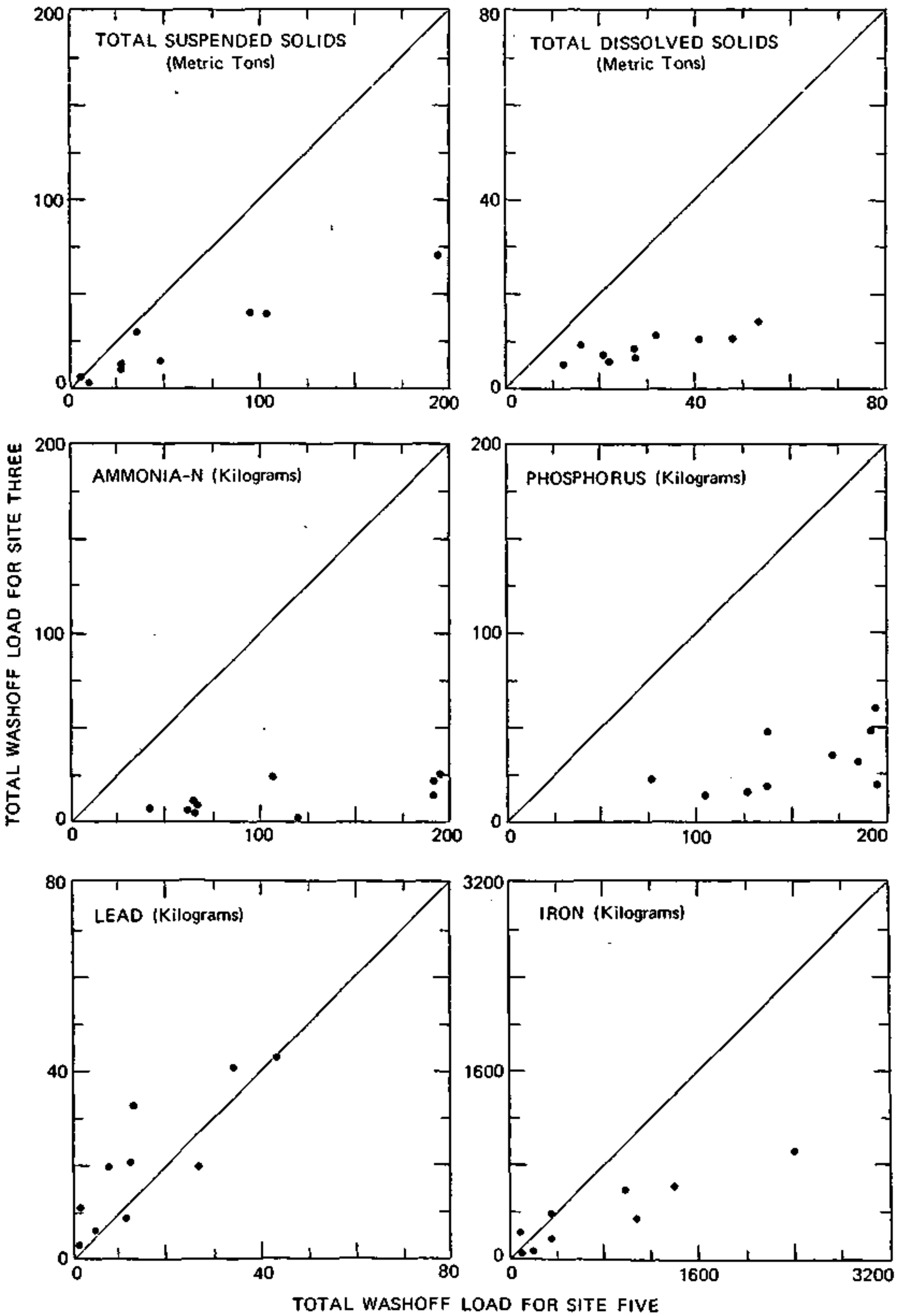


Figure 6.9. Event washoff loads - site 3 vs. site 5

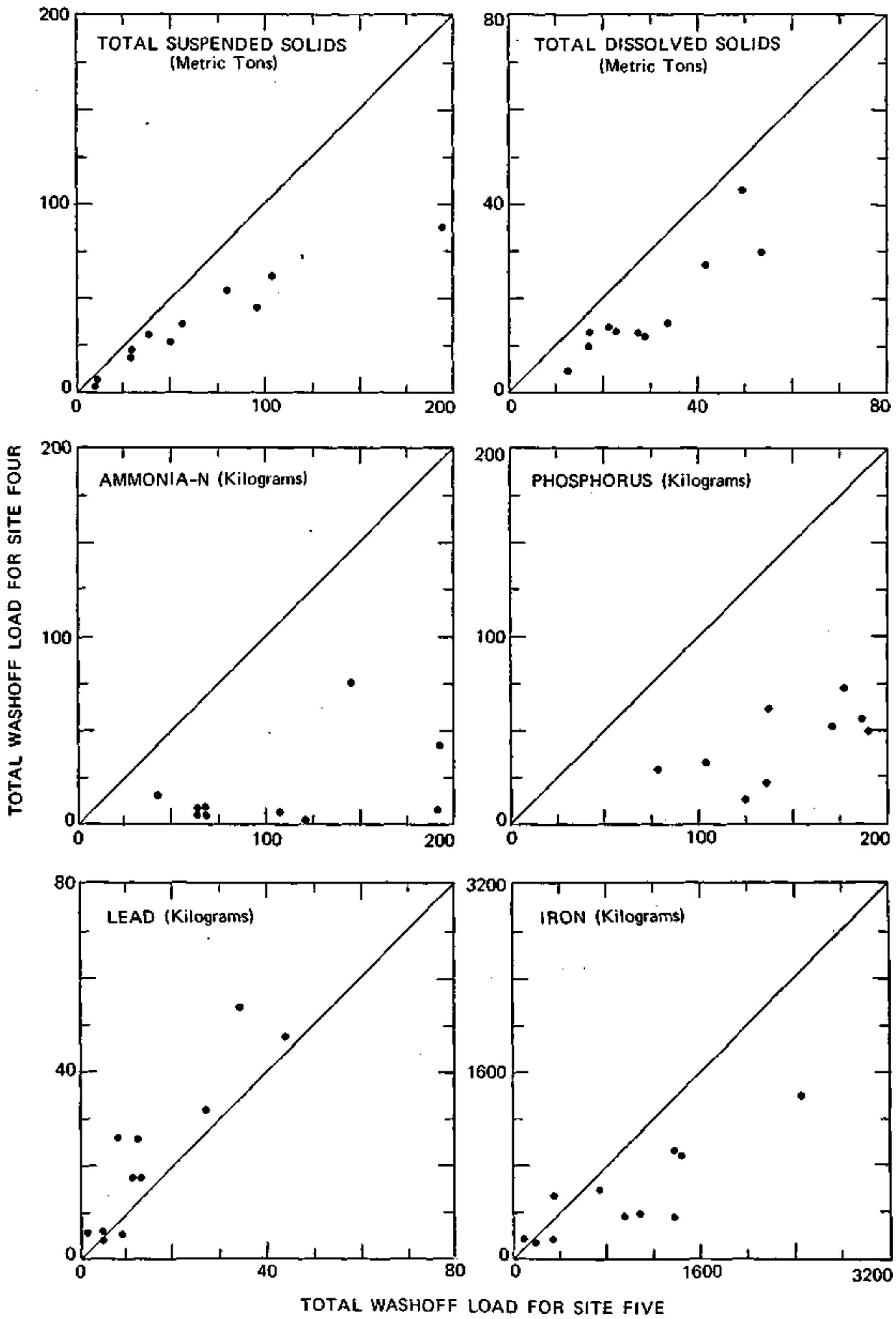


Figure 6.10. Event washoff loads - site 4 vs. site 5

a very strong relationship between the mass of additional solids and peak discharge (squares), a slightly weaker relationship between mean discharge and the additional solids (triangles), and an unclear relationship between dry days and the increase in solids (all circles). Closer inspection of the data indicates that the two data points for dry days that fall to the upper left of the indicated trend line (open circles) represent events where the upstream flows at site 1 were already relatively high at the start of the event. The remaining data for dry days seem to indicate that more material may be seen in the reach as the length of the dry period increases. This can be interpreted to mean that silts and clays from the upstream agricultural basin that are free of lead may be settling to the streambed during periods of low flow between events, and that the longer this dry period lasts, the greater the mass of lead-free available fines for resuspension becomes. This information supports the result of an increase in TSS without an increase of lead, but it does not explain the decrease in lead. It is conceivable that lead adsorbs to the available lead-free sediment particles, not all of which are resuspended.

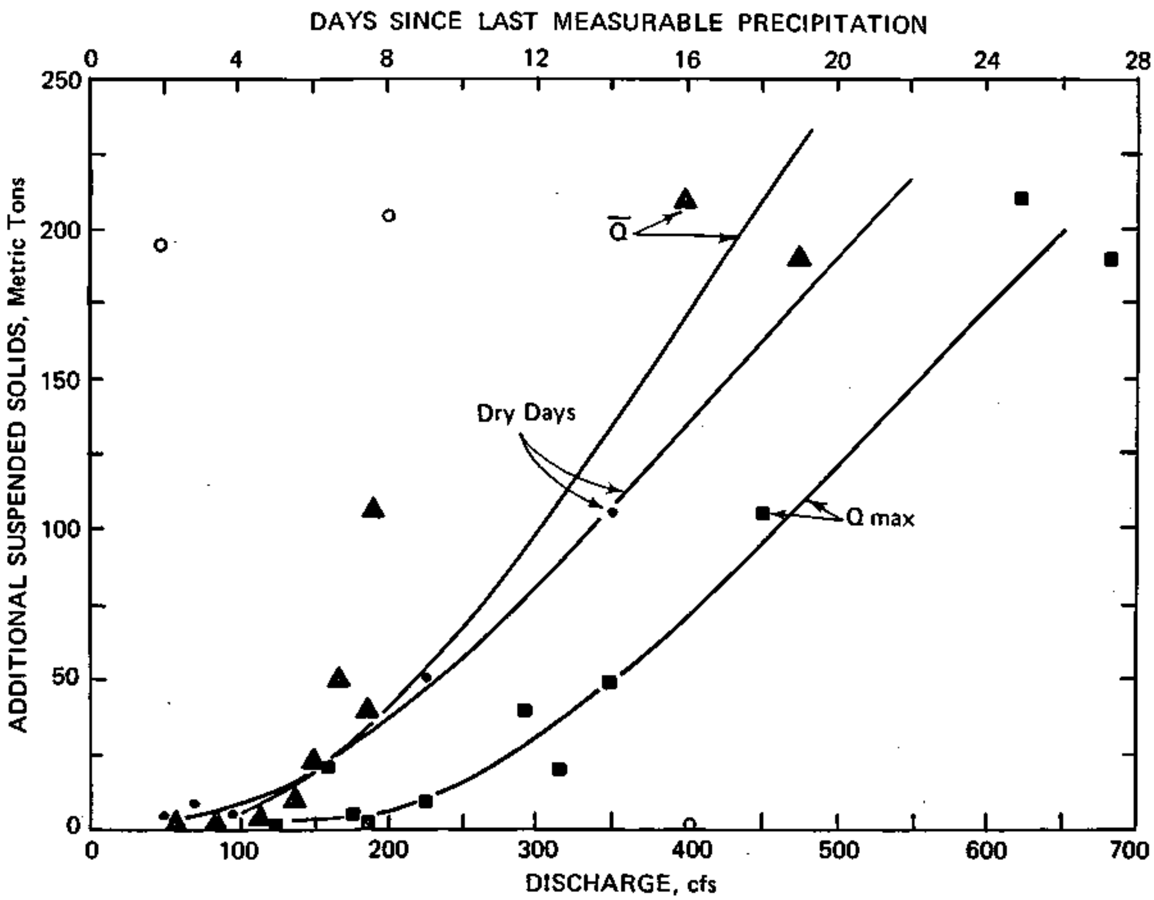


Figure 6.11. Solids load difference vs. event parameters

REGRESSION ANALYSIS

To evaluate the relationships of these six parameters further, as well as to provide a predictive algorithm for the parameters at each site, a regression analysis of the data was performed using stepwise multiple regression. The analysis was performed first by analyzing data from the two urban sites (sites 2 and 3) and deriving equations for urban washoff. Data for sites 2 and 3 were then combined and analyzed for the total urban area (indicated by "URB" in the site column of table 6.1). The three sites on the receiving stream (sites 1, 4, and 5) were then analyzed, with an attempt to indicate the effect of the urban discharge on the two downstream receiving water sites. The resulting regression coefficients are shown in tables 6.1 and 6.2.

For both sites in the urban area, table 6.1 shows that the mean discharge (QBAR) is a function of the average rainfall intensity (TRAIN/DUR), the total rainfall (TRAIN), and the antecedent moisture condition (1/DRY). This is a similar relationship to that derived in many empirical equations for urban runoff. The general equation for QBAR, which is also a function of urban impervious area, also shows this relationship. On the receiving stream, table 6.2 shows that the mean discharge upstream from the urban area (site 1) is strongly dependent on the antecedent moisture condition and the duration of the storm. Immediately downstream from the urban area (site 4) there is reflected a combination of the upstream conditions and urban conditions.

In the urban area, peak discharge is a function of total rain, rainfall intensity, and peak rainfall intensity. At the upstream site on the Saline Branch, the peak discharge is a function of the same parameters as was the mean discharge, with maximum rainfall intensity becoming the

Table 6.1. Regression Analysis Results for Urban Sites

Y = A * AREA^B * DRY^C * TRAIN^D * DUR^E * MAX5^F * QBAR^G * QPK^H

PARAM	SITE	LOAD/EMC	A	B	C	D	E	F	G	H	NS	COR
QBAR	2		73.28		-0.148	0.381	-0.215				9	.812
QBAR	3		183.2		-0.165	0.518	.-0.176				14	.805
QBAR	DEB		73.57	1.979	-0.153	0.458	-0.183				23	.793
QPK	2		123.			0.654	-0.126	0.195			.9	.921
QPK	3		325.1			0.591	-0.094	0.358			14	.923
QPK	ORB		124.	2.098		0.601	-0.106	0.296			23	.914
TSS	2	LOAD	0.0000824						0.689	2.141	9	.971
TSS	3	LOAD	0.00525				1.435				14	.923
TSS	ORB	LOAD	123.3	2.547		0.812					23	.790
TSS	2	EMC	115.3			-0.950	1.057				9	850
TSS	3	EMC	179.9			-0.332	0.753				14	779
TSS	ORB	EMC	132.1	0.960		-0.353	0.791				23	.746
TDS	2	LOAD	3.890			0.446					9	.714
TDS	3	LOAD	10.05			0.488					14	*761
TDS	ORB	LOAD	12.72	2.181		1.195					23	.790
TDS	2	EMC	129.4			-0.467					9	.775
TDS	3	EMC	130.3			-0.417					14	901
IDS	ORB	EMC	122.5	0.0149		-0.474					23	.823
NH4	2	LOAD	5.421		-0.493	-0.347					9	.817
NH4	3	LOAD	16.57		-0.363	0.135					14	.517
NH4	ORB	LOAD	4.471	2.413	-1.610	0.419					23	.750
BH4	2	EMC	0.217						1.396	-1.159	9	.951
NH4	3	EMC	3.758						0.125	-0.152	14	.904
NH4	ORB	EMC	0.115	0.267		-0.785					23	.753
P	2	LOAD	"o.539			0.590			0.907		9	.961
P	3	LOAD	0.182			0.312			1.157		14	.908
P	ORB	LOAD	0.114	-2.345		0.0972			1.870		23	.910
P	2	EMC	0.0126			-0.364			1.006		9	.880
P	3	EMC	0.0438			-0.370			0.536		14	.545
F	ORB	EMC	3.343	2.691		0.196			-0.560		23	.414
PB	2	LOAD	3.097					0.909			9	.858
PB	3	LOAD	6.808					0.960			14	.824
PB	ORB	LOAD	3.173	1.701				0.938			23	.840
PB	2	EMC	0.377				-0.433	0.323			9	.778
PB	3	EMC	0.320				-0.207	0.230			14	.544
PB	ORB	EMC	0.365	-0.354			-0.279	0.277			23	.638
FE	2	LOAD	0.323					0.382	1.452		9	.292
FE	3	LOAD	1.					0.716	1.158		14	.952
FE	ORB	LOAD	74.38	2.441		0.714		0.391			23	.839
FE	2	EMC	5.754			0.253		0.830	1.809	-1.583	9	.936
FE	3	EMC	4.892			-0.286		0.866	0.818	-0.738	14	.827
FE	ORB	EMC	0.616	-0.351		-0.457		0.710	1.120	-0.588	23	..856

PARAMETER	DEFINITION	DBITSCLOADS/EMC)
AREA	URBAN IMPERVIOUS AREA	SQ. HI.
DRT	DRY DAYS SINCE LAST MEASURABLE RAINFALL	DAYS
TRAIN	TOTAL EVENT RAINFALL	INCHES
DDR	DURATION OF EVENT RAINFALL	HOURS
HAX5	MAXIMUM FIVE MINUTE RAINFALL INTENSITY	IN / HR
QBAR	EVENT HEAN DISCHARGE	CFS
QPK	EVENT PEAK DISCHARGE	CFS
TSS	TOTAL SUSPENDED SOLIDS	HETRIC TONS / MGL
TDS	TOTAL DISSOLVED SOLIDS	METRIC TONS / MGL
NH4	TOTAL AMMONIA NITROGEN	KILOGRAMS / HGL
F	TOTAL PHOSPHORUS	KILOGRAMS / MGL
PE	TOTAL LEAD	KILOGRAMS / MGL
FE	TOTAL IRON	KILOCRAMS / HCL
NS	NUMBER OF SAMPLES USED IN ANALYSIS	
COR	MULTIPLE CORRELATION COEFFICIENT	
A	COEFFICIENT OF REGRESSION EQUATION	
B-H	EXPONENTS OF REGRESSION EQUATION	

Table 6.2. Regression Analysis Results for Receiving Stream Sites

$$Y = A * DRY^{C} * TRAIN^{D} * DUR^{E} * MAX5^{F} * QBAR^{G} * QPK^{H}$$

PARAM	SITE	LOAD/EMC	A	C	D	E	F	G	H	NS	COR
QBAR	1		43.25	-0.593		0.643	0.164			8	.877
QBAR	4		299.4	-0.215	0.783					10	.931
QBAR	5		257.6	-0.162	0.953	0.131				11	.884
QPK	1		52.12	-0.148		0.733	0.258			8	.858
QPK	4		385.5	-0.0548	0.570		0.342			10	.916
QPK	5		389.9	-0.0823	0.825		0.196			11	.891
TSS	1	LOAD	0.00646						1.588	8	.920
TSS	4	LOAD	0.00124						1.735	10	.915
TSS	5	LOAD	0.0000776						2.380	11	.968
TSS	1	EMC	20.56				0.432		0.425	8	.989
TSS	4	EMC	257.6				0.622			10	.907
TSS	5	EMC	3.802				0.567		0.781	11	.915
TDS	1	LOAD	0.0773					1.269		8	.986
TDS	4	LOAD	0.0809					1.065		10	.941
TDS	5	LOAD	0.258					0.954		11	.886
TDS	1	EMC	268.5	0.0688			-0.120			8	.624
TDS	4	EMC	221.3		-0.130				-0.138	10	.678
TDS	5	EMC	1001.		-0.189				-0.231	11	.726
NH4	1	LOAD	0.124				-0.164		0.748	8	.987
NH4	4	LOAD	0.171					1.847	-0.866	10	.885
NH4	5	LOAD								11	.000
NH4	1	EMC	0.0871		0.0454		-0.0643	0.0442		8	.963
NH4	4	EMC	0.152		-0.302		-0.246			10	.724
NH4	5	EMC	1167.					-1.404		11	.805
P	1	LOAD	0.0618				0.217		1.088	8	.994
P	4	LOAD	11.37		0.822				0.313	10	.935
P	5	LOAD	157.9		0.453		0.304			11	.776
P	1	EMC	0.135	-0.211				-1.096	1.124	8	.972
P	4	EMC	1.108		0.306	-0.352				10	.724
P	5	EMC	98.4				0.423	-0.882		11	.884
PB	1	LOAD	10.28		0.855					8	.820
PB	4	LOAD	9.120				0.819			10	.722
PB	5	LOAD	16.44		1.409		0.383			11	.827
PB	1	EMC	0.0986	0.309	0.956		0.144			8	.857
PB	4	EMC	2.895				0.949		-0.561	10	.853
PB	5	EMC	0.111		0.304		0.611			11	.736
FE	1	LOAD	3.319		0.529				0.760	8	.993
FE	4	LOAD	0.919				0.573		0.984	10	.878
FE	5	LOAD	0.0276		0.450				1.863	11	.982
FE	1	EMC	11.12	-0.121	0.469			-1.069	0.654	8	.960
FE	4	EMC	12.20				0.703	0.408	-0.542	10	.724
FE	5	EMC	0.113				0.497		0.689	11	.970

PARAMETER	DEFINITION	ONITS(LOADS/EMC)
AREA	URBAN IMPERVIOUS AREA	SQ. MI.
DRY	DRY DAYS SINCE LAST MEASURABLE RAINFALL	DAYS
TRAIN	TOTAL EVENT RAINFALL	INCHES
DUR	DURATION OF EVENT RAINFALL	HOURS
MAI5	MAXIMUM FIVE MINUTE RAINFALL INTENSITY	IN / BR
QBAR	EVENT MEAN DISCHARGE	CFS
QPK	EVENT PEAK DISCHARGE	CFS
TSS	TOTAL SUSPENDED SOLIDS	METRIC TONS / MGL
YDS	TOTAL DISSOLVED SOLIDS	METRIC TONS / MCL
NH4	TOTAL AMMONIA NITROGEN	KILOCRAMS / MCL
P	TOTAL PHOSPHORUS	KILOCRAMS / MCL
PB	TOTAL LEAD	KILOGRAMS / MCL
FE	TOTAL IRON	KILOGRAMS / MCL
NS	NUHBER OF SAMPLES USED IN ANALYSIS	
COR	MULTIPLE CORRELATION COEFFICIENT	
A	COEFFICIENT OF REGRESSION EQUATION	
C-H	EXPONENTS OF REGRESSION EQUATION	

dominant factor and initial conditions (1/DRY) being less prominent. At the two downstream sites, the peak discharge is primarily a function of the total rain and the five-minute maximum rainfall.

The TSS load in the urban area is related to peak discharge, and somewhat less related to mean discharge at site 2. In the general urban equation, the dependence on discharge was eliminated in favor of total rainfall, even though the correlation coefficient drops significantly. The basis for this decision was that in applying these general equations to other urban areas, a stream may not be gaged or may have hydraulic restrictions that can bias the use of discharge values in the equation. In the Saline Branch, all three sites are also dependent on peak discharge to estimate the suspended solids load.

The EMC for TSS in the urban area appears to vary inversely with the total rainfall and directly with the duration of rainfall. Since dry days did not appear in the expression, it would seem that the urban area is an undepletable source of suspended solids. The EMCs on the Saline Branch, on the other hand, are dependent on the peak discharge and peak rainfall. The correlation of TSS with peak rainfall and discharge in the upper reaches of the Saline indicates that the concentration is a function of both resuspension in the channel and of particle detachment and removal from farmlands. The loss of peak discharge as a significant parameter at site 4 would seem to imply that the urban washoff is a much greater source of material in this area, while site 5 again becomes dependent on the peak discharge and peak intensity.

The EMCs for TDS are inversely proportional to the square root of the total rainfall in the urban area, which means that the concentration may be assumed to decrease with increasing rainfall, although the load increases.

On the receiving stream, the dissolved solids concentration is decreasing as maximum rainfall (and therefore mean and peak discharge) is increasing at the upstream site. This concentration increases with preceding dry periods. At the two downstream sites, the EMC decreases with both increasing total rain and increasing peak discharge. The concentration at site 5 decreases more slowly with each of these parameters than at site 4 due to the influence of the treatment plant.

Phosphorus loads in urban runoff are related to the total rainfall and the mean discharge. The loads upstream in the Saline Branch are related to the maximum five-minute rainfall and the peak discharge. Just below the urban area at site 4 the loads become strongly related to total rainfall and peak discharge, although the relationship to peak discharge is weaker than at site 1. This shift in relevant parameters is due to the influence of the urban load. At site 5, the discharge term drops out and is replaced by peak rainfall.

The lead loads in the urban area are totally dependent on the five-minute maximum rainfall. This implies that the lead loading to urban streams depends on the ability to generate scouring surface flows on urban streets. The lead load at site 1 is dependent only on total rainfall, which suggests that rainfall volume alone is required to move water from rural roads to the receiving stream. At site 4 the lead load becomes dependent only on the peak rainfall intensity, indicating that the urban area is the source of lead at site 4. At site 5, the exponent for maximum precipitation intensity drops significantly, while the relationship to total rainfall reappears as at site 1. The higher value of the total rainfall exponent for site 5, along with the dependence on maximum rainfall, means that the loads at site 5 will be higher than at site 1, as was seen in figure 6.8. The relative magnitudes of the two exponents at site 5 versus the exponents of peak rainfall at sites 3 and 4 mean that for most cases, the total lead load at site 5 will be less than those at sites 3 and 4 for the same rainfall data. This conclusion is also consistent with those drawn for lead after inspection of the scatter diagrams.

The EMCs for lead in the urban area are related to the peak rainfall intensity and to the inverse of the rainfall duration. This means that higher concentrations can be expected both from intense rainfall and from short duration storms. The lead EMC at the upstream sampling station on the Saline Branch is dependent on the length of the preceding dry period, on the total rainfall, and on the five-minute maximum rainfall intensity. This indicates that the lead, primarily if not exclusively from rural roadways, is dependent on the accumulation and the volume of rainfall available to move it from the roadways to the stream. The peak intensity of the rainfall governs the magnitude of the EMC which varies only slightly. At the sampling station below the urban outfall, the EMC for lead is a function of the maximum rainfall intensity and the inverse of peak discharge. By substituting for the peak discharge term, the event mean concentration for lead at site 4 becomes:

$$PB_4 = 0.103 \quad DRY^{0.0307} \quad TRAIN^{-0.319} \quad MAX5^{0.797} \qquad (6.1)$$

This equation shows that lead concentrations below the urban area are only slightly dependent on the dry period, and that they are primarily dependent on the maximum five-minute rainfall intensity, which reflects the urban influence on the stream.

At site 5, the EMC for lead is a function of the total and maximum rainfalls. The absence of a factor for dry days, coupled with the reduction in the exponent for maximum rainfall and the change of sign for the total rainfall exponent, supports the previous statements regarding the loss of suspended lead in the reach. The lead concentration at site 5 will exceed that at site 4 only in cases where there is a relatively low intensity rainfall with a large amount of rain, which relates to low surface runoff velocities and slowly increasing flows.

The expressions generated from the available data seem to reinforce the observations made on the basis of scatter diagrams earlier in this section. They offer a convenient means of generalizing the results of the study but are based on limited data. A larger receiving stream, for example, would no doubt have produced different expressions for sites 1, 4, and 5. Similarly, the general urban expression is limited by the fact that only two values of the area variable occurred in the data.

LOG-NORMAL ANALYSIS

A form of data analysis different from the comparison of results from individual basins for single events involves the use of all data obtained at a site to identify characteristic responses to storms. Both USEPA's evaluations of the entire NURP data base[11] and ISWS's investigations of its full records at each site showed that the log-normal distribution was most descriptive of the data. For each constituent monitored, the EMC or load data for all events at one site were fitted to a log-normal distribution and the resulting line was plotted with its 90 percent confidence band. Figure 6.12 is an example of such a plot; it features the EMCs of TSS for all events at site 3. Figures with similar features were drawn for every site and compared to each other to provide the basis for this analysis. Tables 6.3 and 6.4 contain characteristics of the log-normal distributions of EMCs and loads, respectively, of 12 constituents at the five sites. The twelve constituents are TSS, TDS, sulfate, chloride, NH3-N, N03-N, TKN, phosphorus, COD, lead, copper, and iron. The tabulated entries presented for each constituent and site include the median of the observed data, the mean (and median) of the log-normal distribution, and the values of the upper and lower 95% confidence interval at the log-normal mean. In the log-normal distribution the mean and median are coincident. This value was selected for use in comparing distributions because it represents the 50 percent exceedance probability; that is, it is the value for which the chances are exactly even that the EMC or load of the constituent during an event will or will not exceed it. Figures 6.13 - 6.20 contain individual plots for EMC or load of eight of the 12 constituents, with each plot consisting of the log-normal distributions for sites 1, 3, 4, and 5. The site 2 results

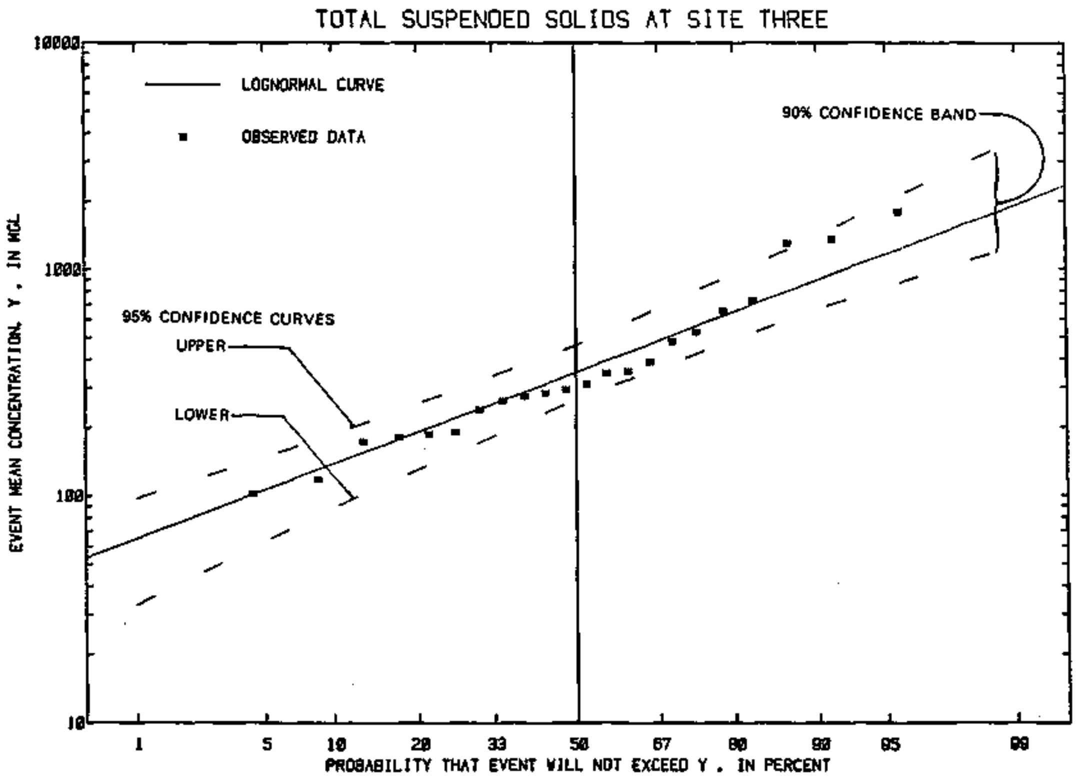


Figure 6.12. Log-Normal distribution of EMCs of TSS for site 3

were not included in these plots because the site 3 data were a more satisfactory representation of the urban area response. The data points and confidence limits also were not plotted, but comparisons of the medians of observed values to log-normal means in the tables provide a measure of the representativeness of the log-normal distributions for each case.

Examination of the EMC summaries, table 6.3 and figures 6.13-6.16, reveals several insights into the performance of the system. For eight of the twelve constituents the levels in the receiving stream are relatively low. For four of the eight there are only small differences between the log-normal means in the Boneyard and downstream in the Saline: for TKN, iron, and TSS, the values are modestly higher at site 5 than at sites 3 and 4, and for COD the values are slightly higher at site 3 than at sites 4 and 5. Phosphorus and NH3-N show much higher levels at site 5 than at all other sites. Lead and copper show their highest values at site 3, with progressively declining levels in the downstream direction. For the remaining four constituents, TDS, chloride, sulfate, and N03-N, the log-normal means at sites 1 and 5 are roughly equal and significantly higher than those at sites 3 and 4.

All these observations and the sequences of mean values between the sites suggest the following characteristics of system function. During storms, relatively high concentrations of TDS, N03-N, sulfate, and chloride in the Saline are diluted by urban runoff, mainly from the Boneyard. Due to inputs from the treatment plant, groundwater, and non-urban surface runoff, these constituents return to levels observed upstream by the time the flow reaches site 5. High concentrations of lead and copper, and to a lesser extent COD, in urban runoff are progressively reduced by dilution and sedimentation during travel down the Saline. Appreciable contributions

Table 6.3. Characteristics of Log-Normal Distributions

of Event Mean Concentrations

	TSS	TDS	SO_4	CL	NH3-N	N03-N	TKN	P	COD	Pb	Cu	Fe
SITE 1												
Median	87	316	36.5	23.2	0.090	11.9	2.00	0.130	43	0.040	0.009	2.00
Mean	164	312	36.6	26.0	0.098	5.13	1.96	0.158	40	0.071	0.011	2.44
Upper	272	340	38.9	31.8	0.103	9.29	3.25	0.218	69	0.115	0.015	3.32
Lower	99	286	34.4	21.2	0.093	2.83	1.18	0.115	23	0.044	0.009	1.80
SITE 2												
Median	301	222	32.0	16.5	0.290	0.900	3.10	0.600	127	0.310	0.069	4.72
Mean	382	196	29.0	16.3	0.232	0.910	3.65	0.647	184	0.377	0.071	5.64
Upper	592	239	34.3	22.8	0.348	1.32	4.96	0.895	272	0.622	0.110	8.'68
Lower	246	161	24.5	11.7	0.154	. 0.625	2.67	0.467	125	0.229	0.046	3.66
SITE 3												
Median	304	200	31.0	13.8	0.255	0.850	3.65	0.595	140	0.320	0.084	6.86
Mean	353	195	29.7	14.4	0.232	0.973	3.51	0.607	161	0.349	0.084	6.46
Upper	463	222	34.6	18.6	0.308	1.21	4.21	0.740	206	0.460	0.111	8.22
Lower	269	171	25.5	11.1	0.174	0.780	2.93	0.498	126	0.265	0.064	5.07
SITE 4												
Median	478	208	32.0	14.3	0.130	2.00	3.40	0.600	130	0.250	0.051	6.17
Mean	372	218	31.0	14.3	0.161	1.84	3.39	0.586	125	0.194	0.046	5.87
Upper	484	247	37.1	19.5	0.214	2.96	3.85	0.701	158	0.278	0.067	7.87
Lower	286	192	25.9	10.5	0.121	1.14	2.99	0.490	98	0.136	0.031	4.38
SITE 5												
Median	524	310	44.0	26.5	0.850	3.70	4.80	1.32	114	0.140	0.036	7.60
Mean	457	307	43.9	26.0	0.991	4.08	4.30	1.42	93	0.112	0.026	7.00
Upper	622	340	50.0	31.4	1.45	5.51	5.08	1.89	115	0.155	0.037	9.48
Lower	335	278	38.5	21.6	0.678	3.02	3.65	1.08	76	0.081	0.018	5.18
WATER QUALITY STANDARDS	none	1000	500	500	1.5	none	none	(.05)	none	0.1	0.02	1.0

All values in mg/1

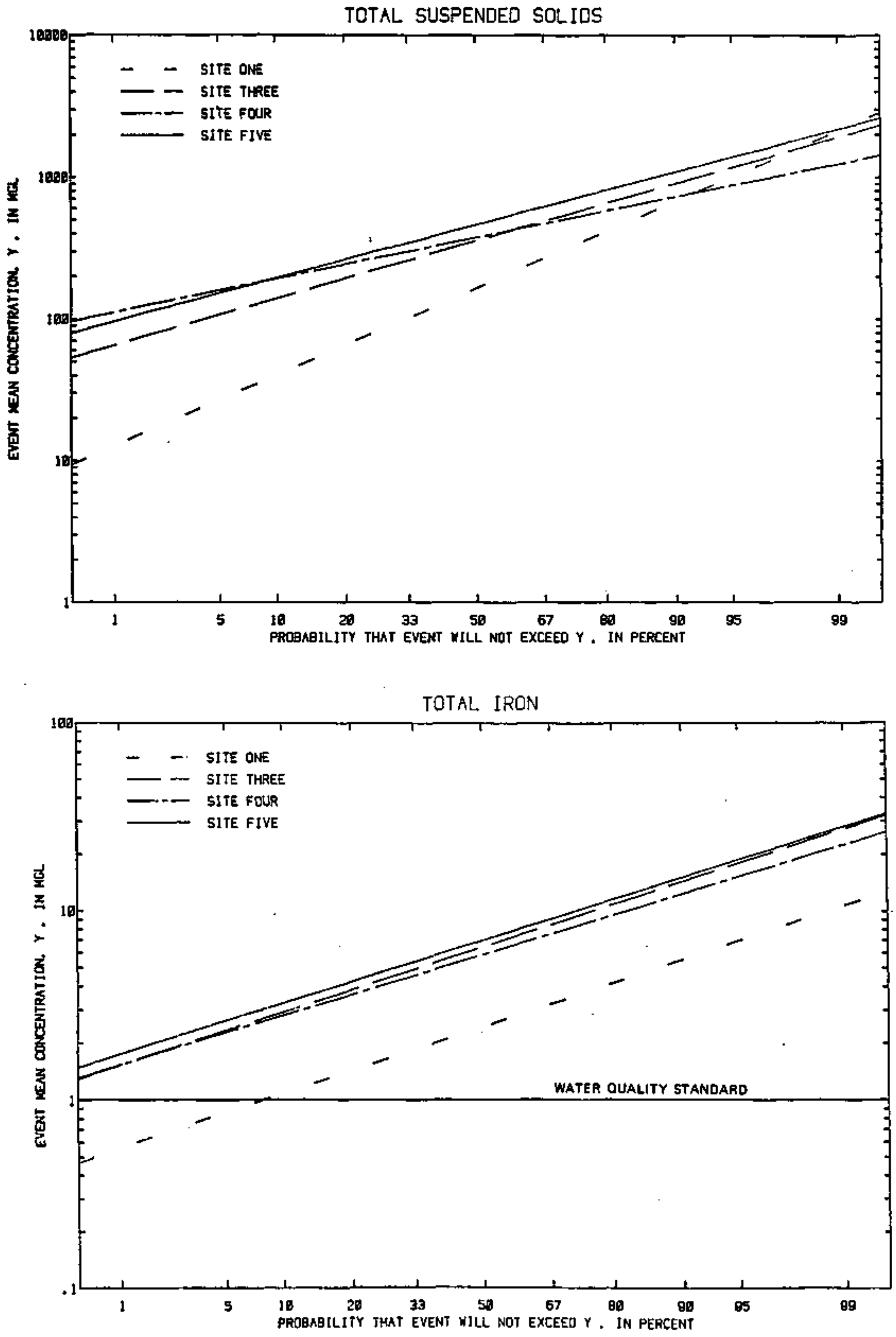
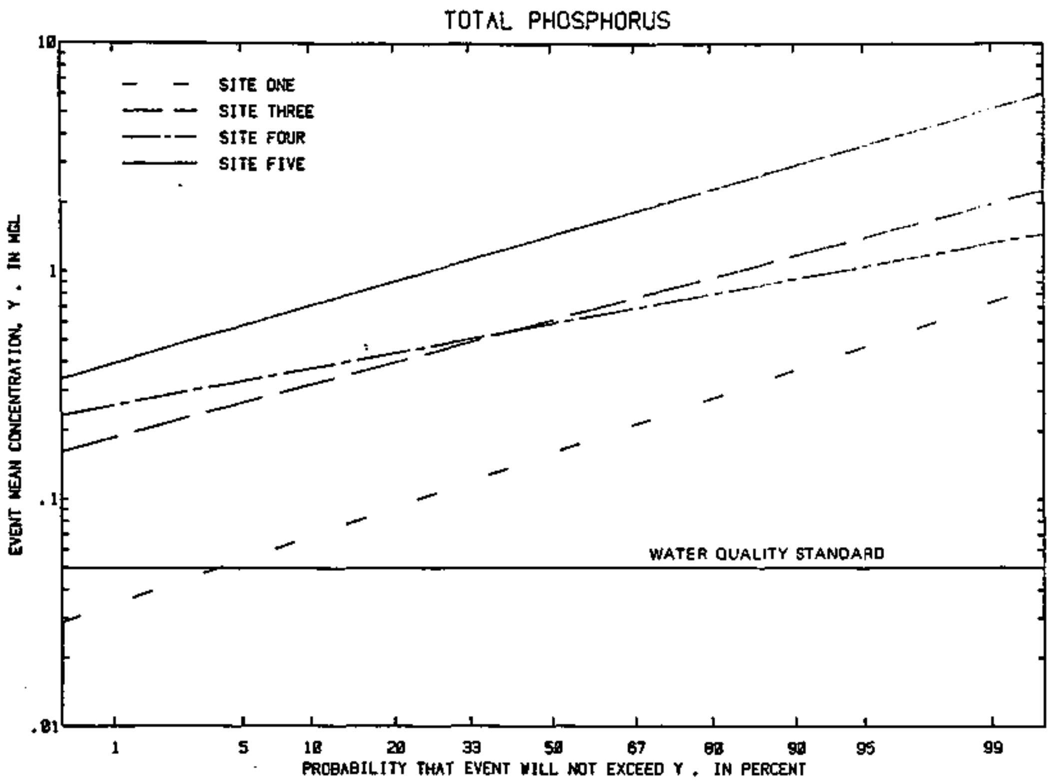


Figure 6.13. Log-Normal distributions of EMCs of TSS and Iron



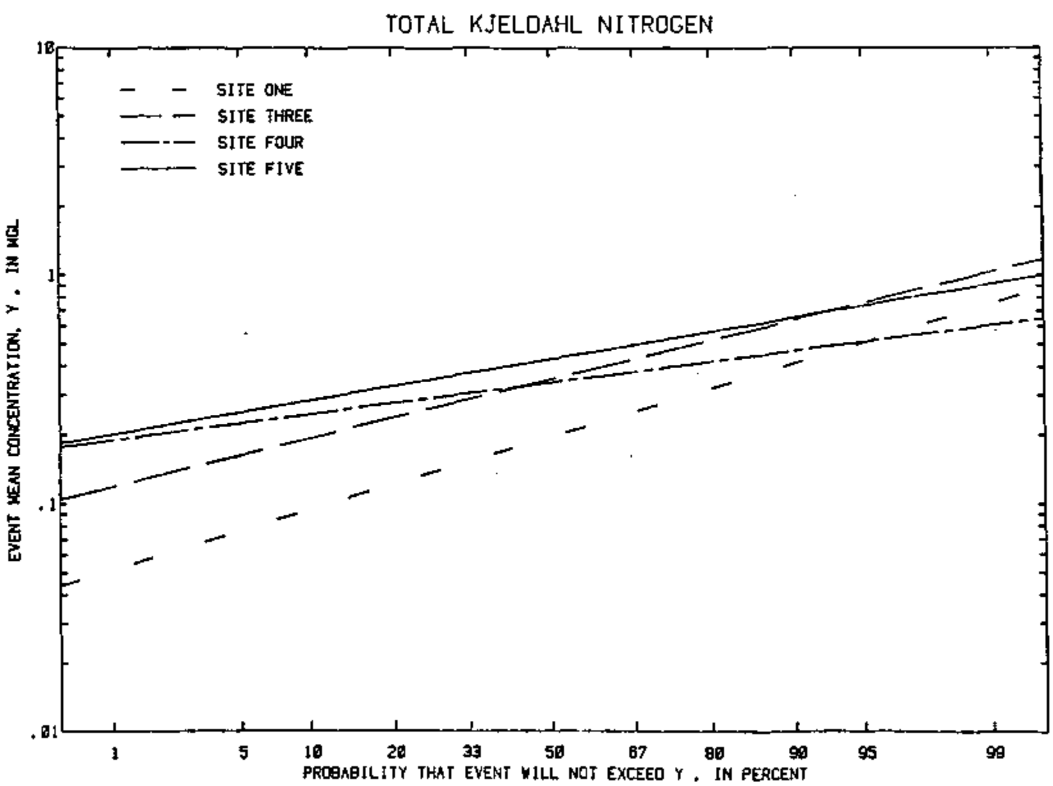
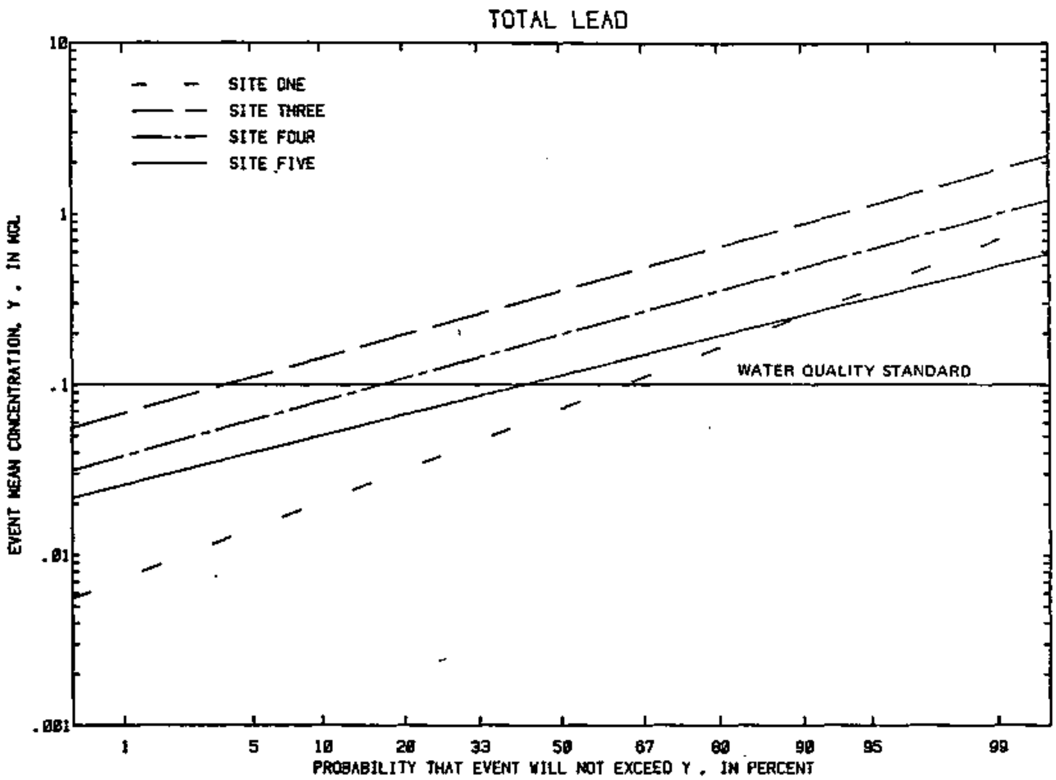


Figure 6.14. Log-Normal distributions of EMCs of Phosphorus and TKN



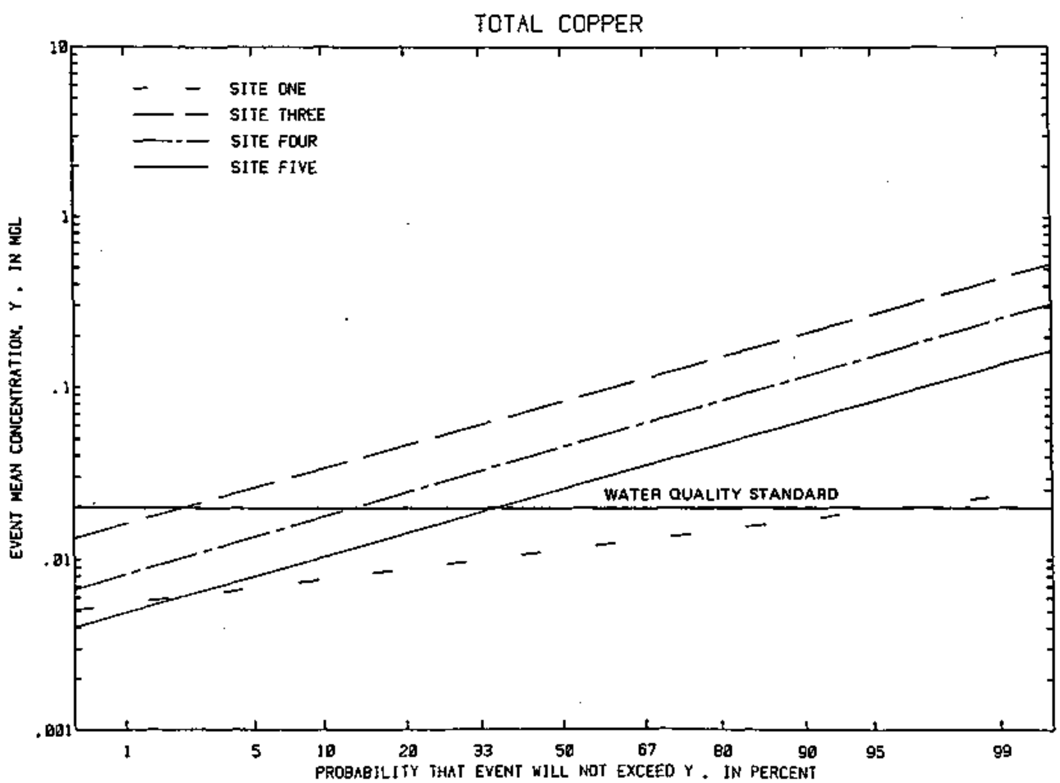
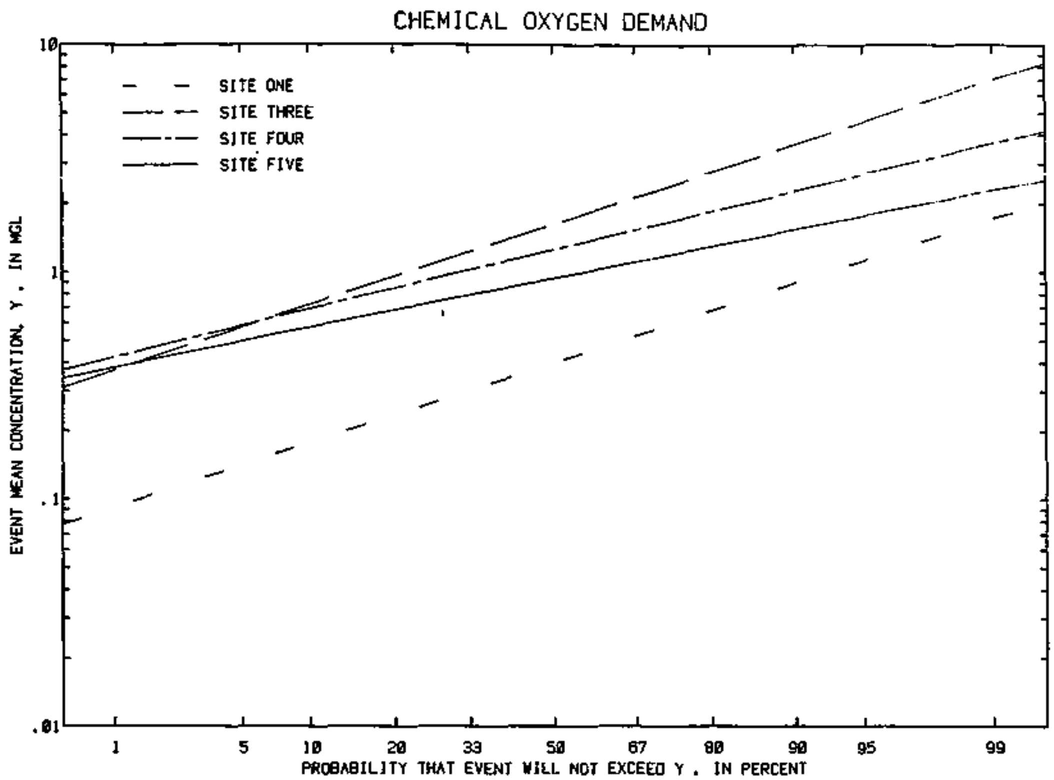


Figure 6.15. Log-Normal distributions of EMCs of Lead and Copper



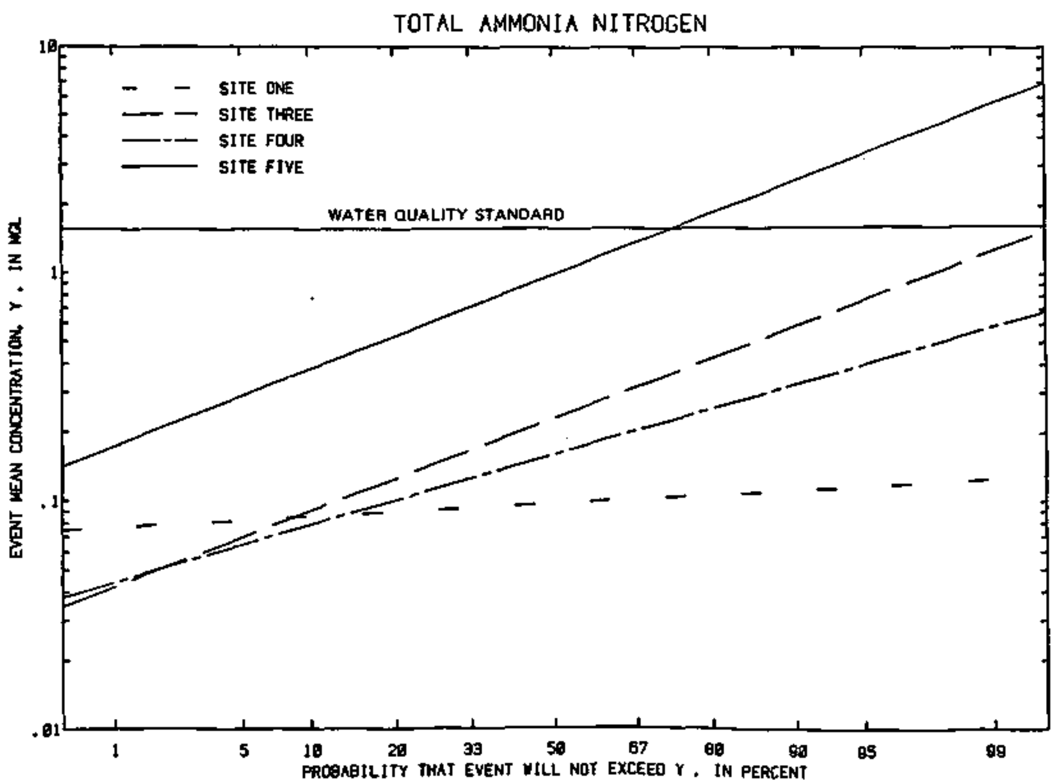


Figure 6.16. Log-Normal distributions of EMCs of COD and NH3-N

of NH3-N, TKN, and phosphorus enter the Saline in urban runoff, but these are relatively small inputs compared to those from the sewage treatment plant effluent. Last, there are large amounts of TSS and iron in the urban flows which raise the receiving stream concentrations. However, in spite of apparent deposition of urban runoff solids suggested by the reduction in lead and copper concentrations, the levels of TSS and iron are highest at the furthest downstream site. This indicates the existence of a non-urban source of solids between sites 4 and 5. This source cannot be the treatment plant, because the solids in its effluent are insufficient to make so large a difference in concentrations.

It is worthwhile to note that due to urban runoff contributions, the general use water quality standards for iron would be expected to be exceeded by the EMCs at sites 3, 4, and 5 for all events. Probability of EMCs of lead and copper exceeding standards at the same sites during storms is also quite high: for lead, 96% at site 3, 82% at site 4, and 58% at site 5; for copper, 98% at site 3, 87% at site 4, and 65% at site 5. If the phosphorus standard were applicable to the Boneyard and Saline, it too would be expected to be exceeded at the three sites during all events. The fact that the probability of the EMC of a constituent exceeding standards is high implies an even higher probability that individual samples taken at the site during a storm would exceed the same standard. Urban runoff is clearly the cause of problems of standards violations in the receiving stream.

Inspection of the loads summaries, table 6.4 and figures 6.17-6.20, show a somewhat different aspect of the system. Because the flow at site 1 was low and nearly constant during most of the monitored events, the loads data for the site do not fit the log-normal distribution well. In earlier

Table 6.4. Characteristics of Log-Normal Distributions of Loads

	TSS	TDS	SO_4	CL	NH3-N	N03-N	TKN	P	COD	Pb	Cu	Fe
SITE 1												
Median	1860	6500	3650	2030	10.0	202.	234.	2.50	6860	7.00	3.00	33.0
Mean	4360	8320	1450	1030	6.64	120.	69.4	5.65	1400	7.09	2.08	50.6
Upper	13400	16400	4670	3080	16.2	380.	454.	14.4	9990	9.99	3.04	127.
Lower	1420	4220	453	346	2.72	38.2	10.6	2.22	197	5.04	1.27	20.1
SITE 2												
Median	8640	3000	481	287	3.50	20.0	65.0	12.0	2920	5.00	2.50	87.0
Mean	6480	3330	492	277	3.67	19.4	61.7	10.7	3110	5.88	2.33	95.5
Upper	11900	4260	610	384	5.75	26.3	95.2	16.8	5190	11.3	3.95	165.
Lower	3510	2600	397	200	2.35	14.3	40.0	6.79	1860	3.06	1.38	55.4
SITE 3												
Median	13300	7990	1150	516	7.50	44.0	134.	20.5	6280	14.0	5.00	278.
Mean	13400	7420	1130	547	7.21	34.0	122.	20.9	5590	11.4	3.70	224.
Upper	20700	8860	1330	656	9.82	45.9	165.	29.5	7950	17.6	5.39	337.
Lower	8730	6220	962	456	5.30	25.2	89.8	14.8	3930	7.44	2.54	149.
SITE 4												
Median	31100	14000	2270	1160	7.00	142.	219.	51.0	9360	18.0	6.00	429.
Mean	28800	16800	2400	1100	8.63	114.	212.	36.6	7800	13.6	5.18	368.
Upper	52400	25600	3430	1730	15.0	247.	332.	56.3	12800	22.6	8.74	645.
Lower	15800	11100	1680	706	4.95	53.0	135.	23.8	4760	8.16	3.07	210.
SITE 5												
Median	49300	41400	6060	2660	121.	511.	464.	172.	10000	12.0	3.00	935.
Mean	60500	40600	5810	3450	118.	486.	513.	170.	10500	12.6	3.39	836.
Upper	101000	55400	7410	4630	159.	832.	671.	210.	16100	20.2	5.51	1370.
Lower	36200	29800	4550	2570	87.7	284.	392.	138.	6810	7.89	2.09	511.

All values in kilograms

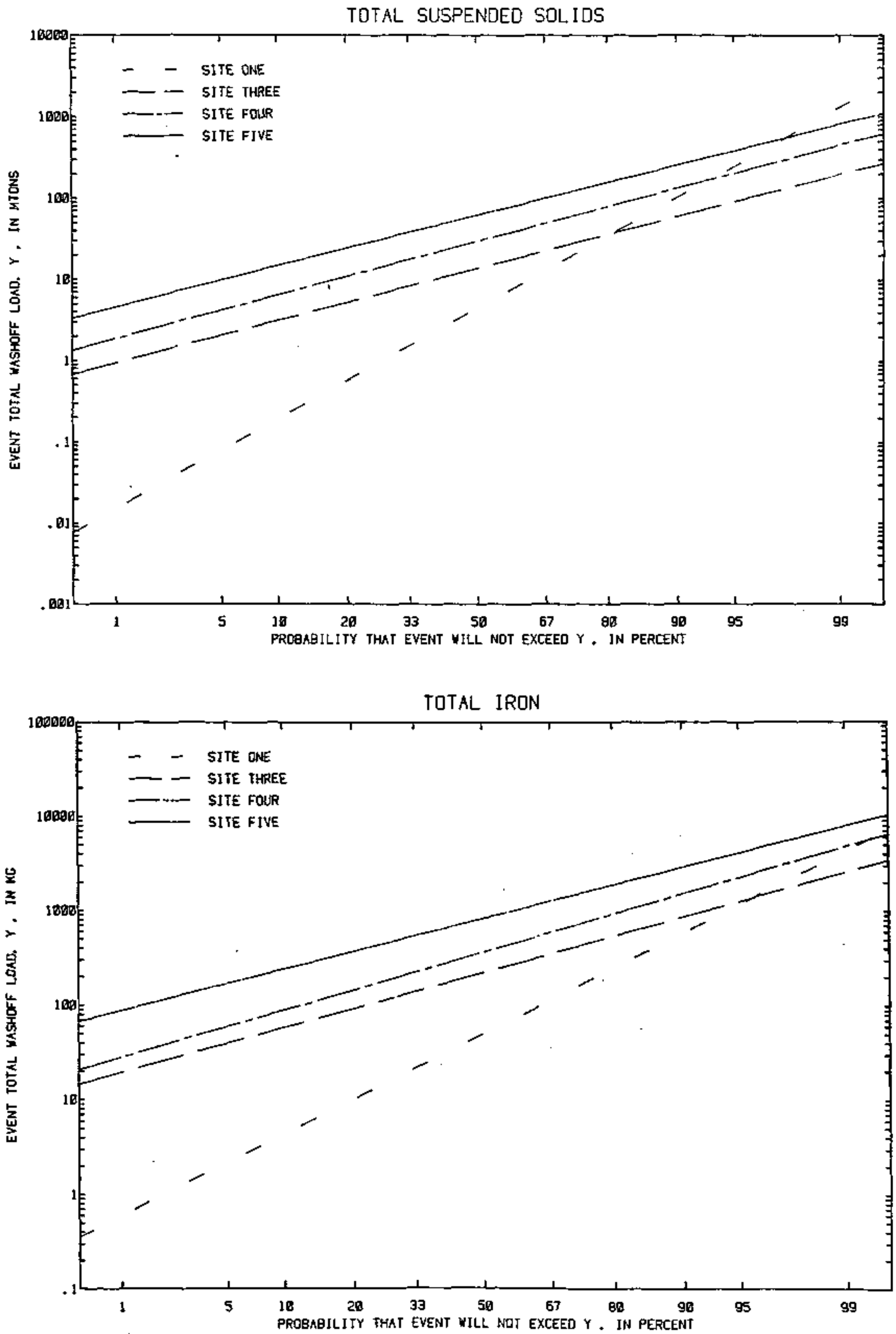
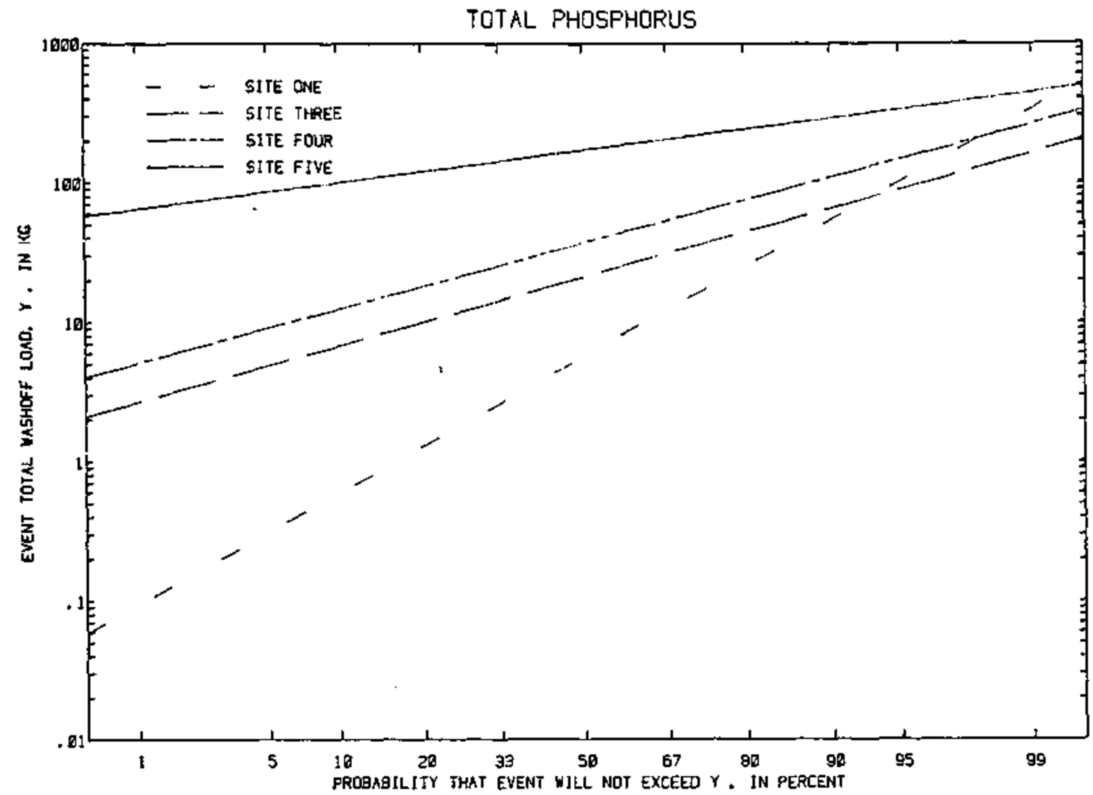


Figure 6.17. Log-Normal distributions of Loads of TSS and Iron



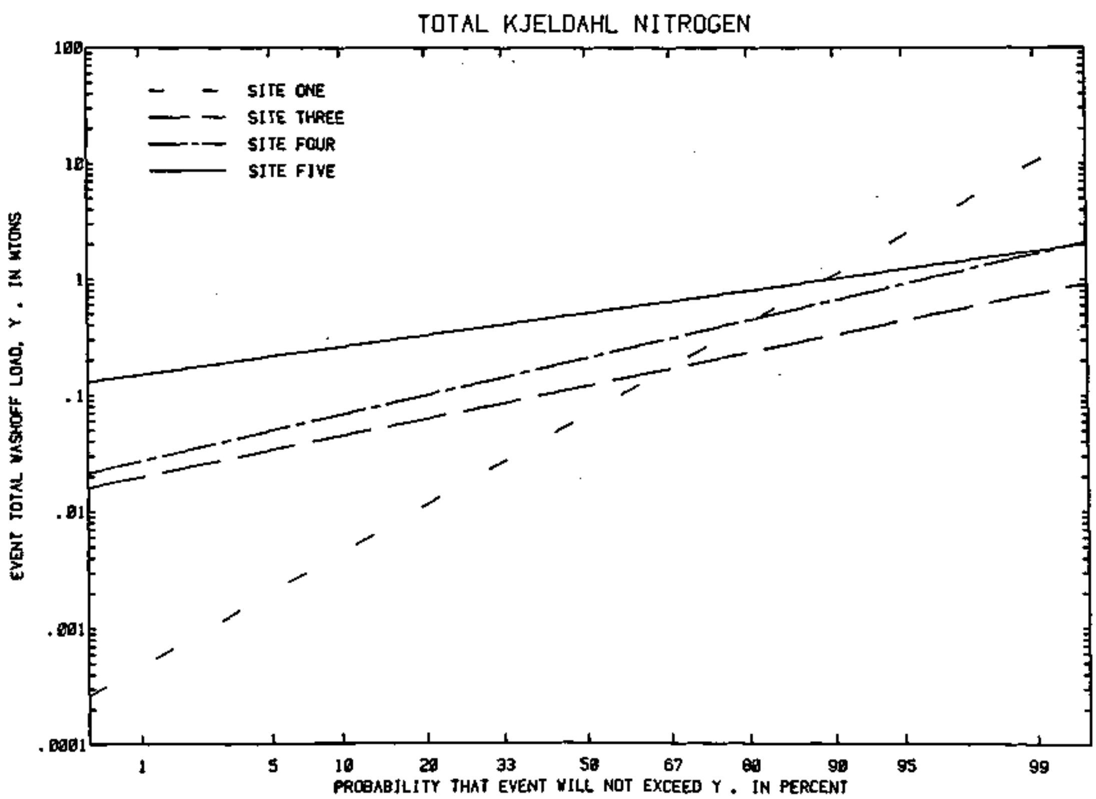
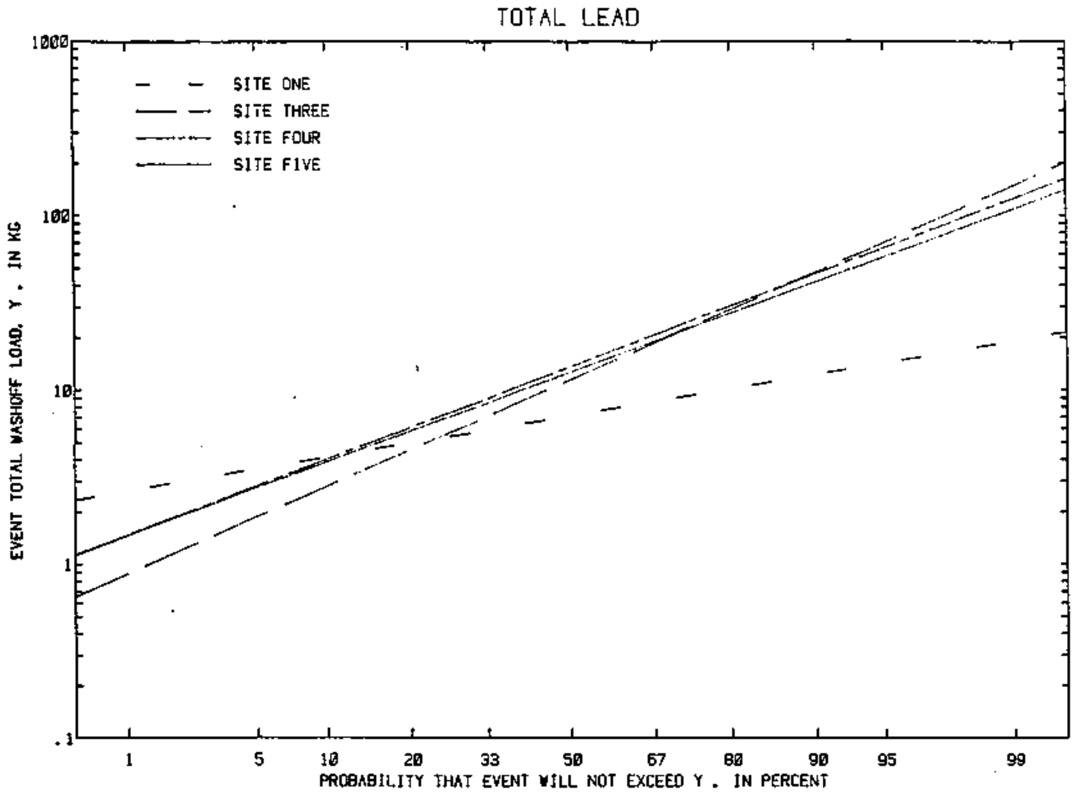


Figure 6.18. Log-Normal distributions of Loads of Phosphorus and TKN



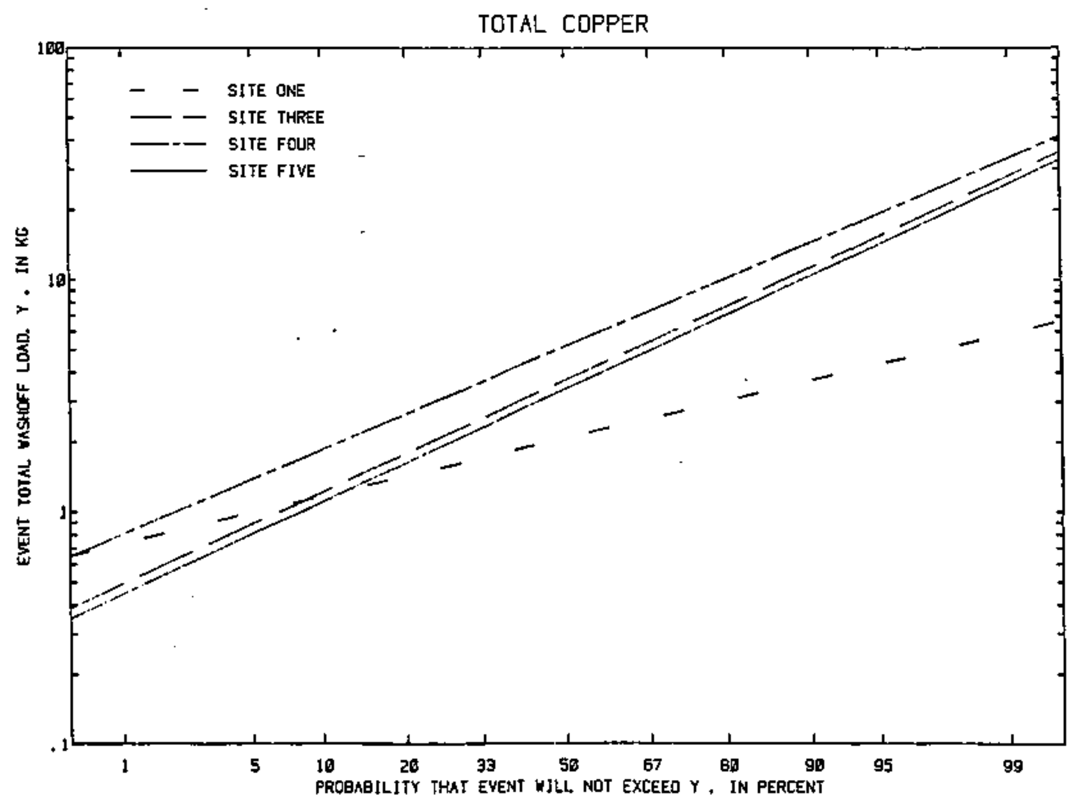
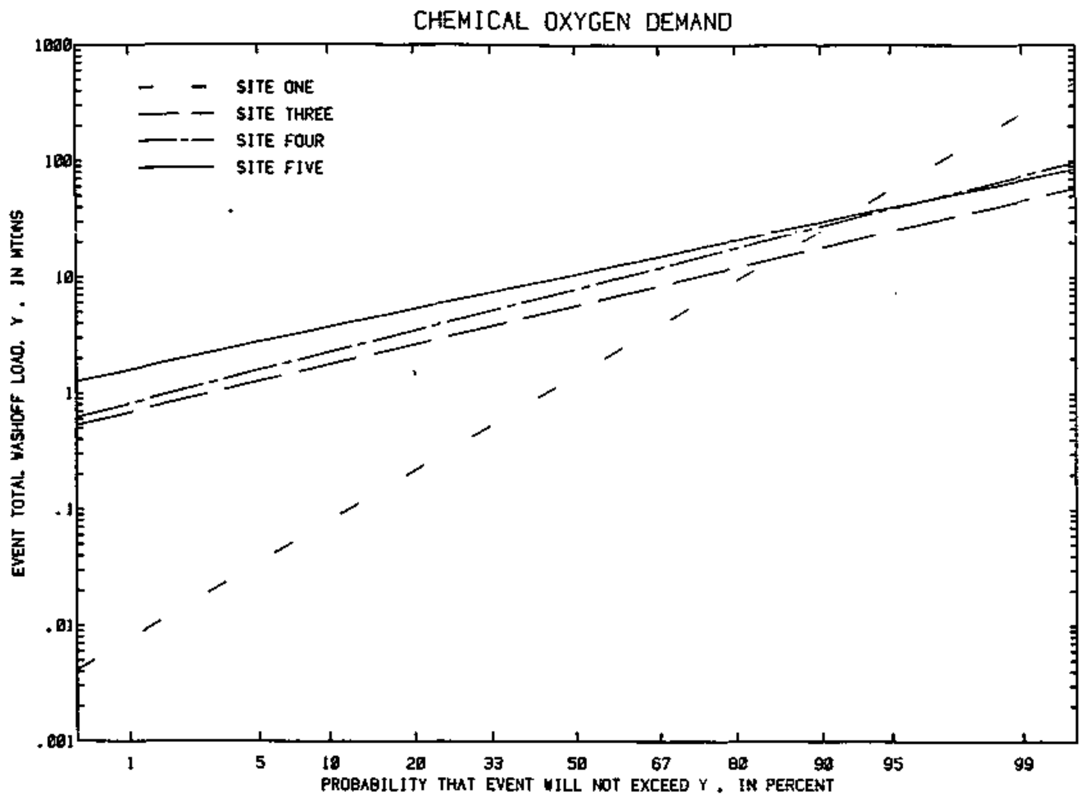


Figure 6.19. Log-Normal distributions of Loads of Lead and Copper



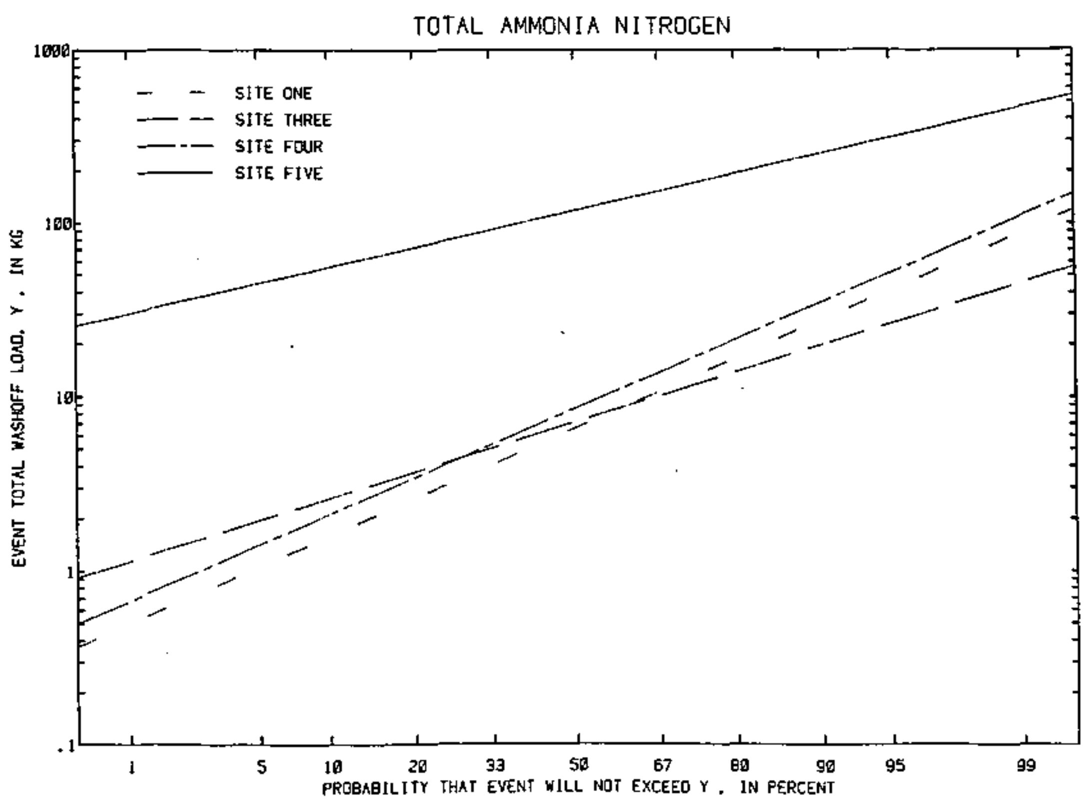


Figure 6.20. Log-Normal distributions of Loads of COD and NH3-N

analysis it was shown that for most events the loads of all constituents at site 1 were much smaller than those at other sites. Therefore this analysis will deal only with comparisons between sites 3, 4, and 5.

There are four basic groupings of the load data for the twelve constituents. For TDS, sulfate, chloride, and N03-N, the loads increase steadily in the downstream direction, with significant differences at the 90% confidence level between the log-normal means at sites 3 and 4 and those at sites 4 and 5. These are the constituents for which the urban concentrations are rather small and the receiving stream levels are large, so that the urban runoff has little diluting effect. The differences between sites 4 and 5 are due mainly to increased streamflow and partially to contributions from the treatment plant. These constituents do not appear in concentrations or loads large enough to merit concern in water quality considerations.

The second grouping of load data features NH3-N, phosphorus, and TKN. For these three the loads also increase in the downstream direction, but there is no significant difference between the log-normal means at sites 3 and 4. However, there are large and definitely significant differences between the means at sites 4 and 5. These are due to the substantial inputs from the treatment plant effluent. As stated previously, the general use water quality standard for phosphorus does not apply here, the new standard for NH3-N is not exceeded, and there is no standard for TKN. Thus, in the sense of standards violations, the concentrations and loads of these three constituents cannot be construed as a problem. The quantities of phosphorus loaded to the stream by the urban area including the treatment plant, however, do seem large enough to deserve some concern.

The third grouping contains the load data for lead, copper, and COD. The first two of these pollutants are distinctly urban in origin, while the third may be attributed largely to urban sources. There are no significant differences between the log-normal means at sites 3 and 4 or 4 and 5 for any of these constituents, though the means are highest at site 4 for lead and copper, and they increase in the downstream direction for COD. The similarity between sites 3 and 4 of loads of all three constituents indicates that the urban area is the dominant source of their loads to the Saline. The similarity of loads between sites 4 and 5 suggests that there are only minor sources or sinks for the pollutants downstream from the urban area. It also shows that the big reduction in log-normal means of EMCs of lead and copper from site 3 to site 5 is probably due more to dilution of urban runoff flows than deposition of urban runoff solids. The increase in the log-normal means of COD loads between sites 4 and 5 is due in small part to input from the treatment plant effluent.

The final grouping features TSS and iron. These two constituents behave similarly to those in the second group, since the log-normal means increase in the downstream direction. The dissimilarity is that the differences between the means at sites 4 and 5 as well as sites 3 and 4 are insignificant at the 90 percent confidence level. The comparison of results from sites 3 and 4 show that the TSS and iron loads at the latter site are principally urban in origin. The comparison for sites 4 and 5 shows that though the broad confidence bands around the log-normal means do intersect, technically making the differences insignificant at the 90 percent confidence level, the means at site 5 are more than twice the means at site 4. The significant differences between sites 4 and 5 for loads of NH_3-N, TKN and phosphorus were attributed to the treatment plant effluent.

The "insignificant" differences for TSS and iron cannot be attributed to the treatment plant, however, since the effluent is low in both constituents. The apparent increase in the downstream direction must be due to other sources, such as erosion of stream banks or resuspension of bottom material, between sites 4 and 5. The fact that the analysis of lead and copper loads suggests that deposition of urban runoff solids might not be occurring makes the thesis of erosion or resuspension of non-urban solids more acceptable.

In summary, these figures and tables give fair representations of the probabilities of responses, in the forms of EMCs and loads of different constituents, at each site. The comparisons of these probable responses indicate much about the function of the drainage system. It appears the upstream flow has a significant influence on the EMCs and loads observed downstream only in late winter or early spring, or during very rare large events. Urban runoff in the Boneyard conveys enough pollutants to the Saline to cause frequent exceedance of water quality standards for lead, copper, and iron in both streams. Iron and TSS are contributed to the Saline not only by urban runoff but also by unidentified downstream sources. Significant quantities of NH3-N, phosphorus, TKN, and COD are delivered to the Saline in urban runoff, but greater contributions to the concentrations and loads of the first three are made by the treatment plant.

SECTION 7

DISCUSSION

The results and analyses of this project show that storm runoff from the urban area affects the receiving stream by elevating concentrations of several constituents well above background levels, and in some cases above water quality standards as well. For lead, copper, and iron, urban runoff is definitely the cause of standards violations in the urban and receiving streams during storms. The facts that exceedances of these standards are relatively brief and that these constituents exist in runoff almost entirely in particulate form, making them less available for uptake by plants and animals, may color the interpretation of the severity of the problem, but do not alter the defined condition of standards exceedance. Unless the water quality standards are revised with respect to the different kind of pollutant load which occurs in urban runoff, the exceedances of standards must continue to be considered problems.

The case of NH3-N provides an interesting sidelight into the definitions of standards and problems. Just after completion of the runoff monitoring program the UCSD started up a tertiary treatment system to remove NH3-N from the effluent before discharge. This has had the effect of reducing the average effluent NH3-N concentration from about 10 mg/1 to about 1 mg/1. Concentrations in the Saline downstream from the plant have declined similarly. However, two months after the NH3-N removal system was started, the Illinois Pollution Control Board revised the general use water quality standard for NH3-N upward from 1.5 mg/1 to 15 mg/1. Most of the prior violation levels of NH3-N in the Saline caused by the treatment plant effluent, and now reduced by the new treatment system, would not be violations under the current standard. Thus there is a continuing possibility for revisions of standards to correspond to changes in perceptions of problems.

The actual hydrologic and water quality responses of the urban and rural portions of the study area were similar to those forecast in planning of the study. Except for periods in late winter and early spring, when flow was high due to snowmelt and spring rains, the agricultural area upstream from the city produced little runoff or pollutant load during storms. The urban area responded quickly and predictably to storms, with rapidly changing flows, high peak flows, and high concentrations and large loads of urban pollutants such as TSS, lead, copper, iron, and phosphorus. The peak flows were generally attenuated by the time the runoff reached the downstream edge of the study area, despite additional inflow from the sewage treatment plant effluent and lateral drainage. Some small parts of the urban loads of lead and copper appeared to have been deposited in the reach between the Boneyard mouth and the downstream site on the Saline. Iron and TSS should have behaved the same way, but instead they increased by the time the flow reached the downstream point, due either to resuspension of bottom material or to unknown additional sources. Loads of NH_3-N, phosphorus, TKN, and COD in urban runoff were substantial, but their effects on the receiving stream constituent levels were less than the effects of the treatment plant effluent. There were three unexpected monitoring results: 1) the magnitude of effect of the sewage treatment plant effluent on the balance of NH_3-N, phosphorus, TKN, and COD in the Saline; 2) the existence of additional sources of solids between sites 4 and 5; and 3) the large proportion of the annual load of solids in the stream transported during the early spring snowmelt period. The last of these suggests that if reduction of the total annual load of solids in the Saline is a major goal, then attention should be focused on the late winter and early spring period, when snowmelt or spring rains will produce high flows and solids levels in the stream. However, if the concern is not solids themselves but urban constituents associated with solids, such as lead and copper, then controls should be aimed at urban stormwater.

Many of the pollutants in urban runoff appeared to travel undiminished out of the study area. This was true especially for those which occurred mainly in dissolved form, such as NH3-N, COD, phosphorus, and TKN. These include the constituents which have major sources in the treatment plant effluent, so it seems safe to say generally that urban runoff effects on the receiving stream with respect to these constituents is small. However, these nutrients may have some influence on dissolved oxygen in the downstream reach of the Saline. The SOD test results indicated no D.O. problems due to benthic bacteria demand but possible problems related to algae in the stream. The algal behavior is influenced by daily and seasonal variation in flow and nutrient supply, which in turn are affected by urban runoff and treatment plant effluent. Algal photosynthesis and respiration cause strong fluctuations of D.O. in the Saline, especially in late summer.

There is evidence that some metals associated with urban solids, such as lead and copper, may be settling out in the downstream reach of the Saline. The main indicators of this possibility are the results of the sediment quality determinations from sites upstream and downstream from the urban area. Concentrations of lead, copper, zinc, chromium, cadmium, and mercury in fine sediments from the downstream sites were two to ten times higher than those from the upstream sites. Although the low percentage of fines in the downstream sediments suggests some flushing of fines from the system, perhaps on an event or seasonal basis, the higher metals concentrations in the remaining fines suggest a potentially serious problem from urban runoff.

The problems caused by temporary exceedance of the water quality standards by urban runoff concentrations are not well-defined. It is not clear whether such levels of pollutants in runoff-receiving streams are harmful to the living creatures in the streams. The results of the fish inventory in the Saline showed essentially no difference between upstream and downstream populations, but in both cases the overall biological condition could only be described as fair to poor. The macroinvertebrate inventory indicated that downstream populations consist mainly of species which can withstand stresses of elevated pollutant concentrations, habitat destruction, extreme variation in flow, and accumulation of pollutants in sediments. Still, if the effects of brief periods of elevated concentrations of pollutants in the stream are not severe, then the long term problems caused by urban runoff might be associated with the physical effects of the flows and the chemical effects of sediment accumulations. The latter would be especially worthy of concern where streams carrying urban solids loads flow into lakes or reservoirs.

Three qualifications should be associated with the results of the study. The first is that the study area contained no real industrial properties; in fact, few of the NURP projects dealt with industrial areas. The second is that the receiving stream in this study does not flow to a lake or reservoir. If it did, as in other locations where similar urban areas drain to streams which do enter lakes, the potential for identifying problems relating to loads of phosphorus and metal-enriched sediments would be much greater. This should be considered if transfer of these findings is attempted. The third is that the receiving stream's potential is limited by its current use. Its principal function is drainage, and the modifications which have been made to it to enhance this function have helped to diminish its other capacities.

Table 7.1 provides the means of comparing the results of urban runoff quality monitoring from this study to those from the previous work in Champaign and from all NURP projects. For the Boneyard Creek at Broadway Avenue, site 3, the medians of the log-normal distributions of the EMCs of 12 constituents are given in the table. Out of the 31 events monitored at the site, there were 18-22 events with EMC data usable for the log-normal distributions of the constituents: TSS, TDS, sulfate, chloride, NH3-N, N03-N, TKN, phosphorus, COD, lead, copper, and iron. The next four sets of entries in the table consist of similar data from the four major basins of the street sweeping evaluation study. The values given are again medians of log-normal distributions of EMCs for all events at a site during periods of no street sweeping on the basin. The number of EMCs in each data set ranged from 13 to 38, depending on the basin and constituent. The final entry, labeled "All NURP," contains data taken from a presentation by USEPA at the final NURP workshop in April 1983. At that time, 23 of the 28 projects had supplied EMC data for 2549 site-events to USEPA. Seven of the 12 constituents in table 7.1 were included in the analysis by USEPA, with data sets ranging from 790 to 1441 values. The table shows the median values of the log-normal distributions of the EMC data sets for the seven constituents.

Examination of the table reveals that the values of nine constituents

Table 7.1. Medians of Log-Normal Distributions of EMCs

SITE	TSS	TDS	S04	Cl	NH3-N	N03-N	TKN	P	COD	Pb	Cu	Fe
	Constituent (mg/1)											
Boneyard Creek at Broadway Site 3, 1981-2	353	195	30	14	0.23	0.97	3.51	0.61	161	0.35	0.08	6.46
Mattis North Site 1, 1980-1	216	152	19	14	0.19	0.72	2.47	0.50	200	0.41	0.04	3.99
Mattis South Site 2, 1980-1	279	125	18	8	0.33	0.69	3.02	0.57	179	0.54	0.03	4.91
John South Site 4, 1980-1	84	141	22	9	0.29	0.94	1.91	0.53	78	0.14	0.04	1.44
John North Site 5, 1980-1	136	133	20	9	0.38	0.89	3.31	0.65	111	0.22	0.04	2.78
All NURP	108	---	--	--	----	0.68	1.50	0.29	71	0.14	0.03	----

are higher for Boneyard Creek than for runoff from the small urban basins. These include some materials primarily in suspended form, such as TSS and iron, and some occurring predominantly in soluble form, such as TDS and sulfate. The COD and lead values for the Boneyard are higher than those for the John Street basins, the residential areas, but lower than those for the Mattis Avenue basins, the commercial areas. The NH3-N value for the Boneyard is lower than that for three of the four basins. The Boneyard Creek basin is much larger than the small urban basins and contains a greater variety of topography, street types, and land uses, including the central business districts of both Champaign and Urbana. The drainage system is also more complex, with storm sewer networks throughout the cities emptying into the channelized stream. Taking these facts into account, and acknowledging that the data collection periods were not the same, it is reasonable to state that the characteristics of storm runoff in the Boneyard are similar to those in runoff from the small urban basins.

However, comparisons of the Champaign values to those of the entire NURP program show that for TSS, TKN, phosphorus, COD, and lead the Champaign values are much higher. Only for copper and N03-N are the Champaign numbers for more than one site close to those given for the "All NURP" collection. It should be recalled that the Champaign study areas were much smaller and quicker to respond to rain than most of the NURP study areas. Because of the differences in size and drainage of the basins, it may be inappropriate to compare results from Champaign to the national figures. Still it demonstrates that runoff measured shortly after leaving streets or traveling through an urban drainage network may display much higher levels of contaminants than the national median values might suggest.

SECTION 8

CONCLUSIONS

1. The primary water quality impact of urban runoff from Boneyard Creek on the Saline Branch receiving stream is the elevation of stream concentrations of lead, copper, and iron to levels 5-10 times background concentrations and well above water quality standards. For these constituents the probability range is 85-100 percent that event mean concentrations for an event will exceed standards in the Saline just downstream from the Boneyard. For total suspended solids, phosphorus, Kjeldahl nitrogen, and chemical oxygen demand, median EMCs in the Saline due to urban runoff range from 4 to 16 times routine background levels.

2. The elevated concentrations of the above-named constituents in the Saline have short durations, generally no more than two to three hours beyond the end of a storm event. Also, previous work has shown that 30 percent of the Kjeldahl nitrogen, 60 percent of the phosphorus, 70 percent of the copper, and virtually 100 percent of the lead and iron are associated with suspended solids.

3. The effluent from the sewage treatment plant has greater influence on receiving stream levels of phosphorus and ammonia-nitrogen than has the urban stream, in storms as well as in dry weather. About 91 percent of the load of ammonia-nitrogen to the Saline during the year of monitoring was attributable to the treatment plant effluent.

4. The total suspended solids load carried by the Saline during the 22-day period of snowmelt runoff monitoring constituted 64 percent of the estimated total TSS load carried by the stream for the entire year of data collection.

5. The urban area constituted only 14 percent of the total study area but produced 28 percent of the annual load of TSS and 95 percent of the annual load of lead.

6. The results of limited sediment sampling showed increased constituent concentrations in fine particles in the downstream direction. Two to fivefold increases were seen for phosphorus, Kjeldahl nitrogen, COD, zinc, and chromium, while tenfold or greater increases were observed for lead, copper, and mercury.

7. Results of constituent loads analysis and sediment sampling indicate possible deposition of urban solids between sites 4 and 5, producing sediments enriched in urban metals such as lead, copper, zinc, chromium, and cadmium. However, the scarcity of fines in sediments of the downstream reaches suggests that most of the urban solids are flushed through the system and out of the study area. The short residence time of urban runoff in the study area prevents assimilation of soluble pollutants and assures that they, too, pass through the system.

8. The characterization of urban runoff indicates that rainfall parameters such as total volume, average intensity, and maximum five-minute intensity have greatest influence on EMCs and loads of constituents in runoff. The length of dry period preceding a storm has no apparent influence on EMCs or loads.

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APPENDIX I

EVENT DATA SUMMARY TABLES

The two tables in this appendix contain summaries of the event data collected during this study at the five sites of the automated network. The hydrologic data are the same in both tables; table I.1 features the EMCs of 15 constituents, while table I.2 contains the event loads of 14 constituents. The data are grouped by event, each entry requiring five lines and separated from the next by a blank, line. In the first column are given the start date by month, day, and year (mmddyy), the start time (0001-2400), and the time elapsed since the last previous recorded rainfall (days x 10^{-2}). The second column contains the site numbers. The third through sixth columns show rainfall characteristics of the event; in order, total rainfall (inches x 10^{-2}), duration of rain (minutes), and average and maximum five-minute intensities (inches per hour x 10^{-2}). Entries are made in the rainfall columns only for sites 1, 2, and 4 because those were the sites equipped with the three automated raingages. The next two columns, labeled RUNOFF, give the gross volume of runoff (GVOL) for the entire event and the concentration volume (CVOL), an estimate used in the calculation of the EMC, which represents the sampled portion of the runoff volume; both of these are in units of cubic feet x 10 . The two tables are identical to this point.

The remainder of table I.1 gives the EMCs for up to 15 constituents sampled during the event. The integer values in a column should be multiplied by 10 raised to the power indicated in the column heading to get the actual EMC. For example, in the event of 101781, the EMC for chloride (CL2) at site 2 is 160 x 10^{-1} = 16.0 mg/1. All EMC data in table I.1 are given in mg/1 (multiplied by 10 raised to some power) except for pH, which has no units, and specific conductance, which has units of micromhos/cm. The presence of a negative value in the table indicates that the result of at least one discrete sample at the site was below detection limits and that an estimated value was used in its place in the EMC calculation. The true EMC would be somewhat less than the value given after the minus sign.

Table I.2 differs from table I.1 in that it contains constituent washoff loads, in kilograms, in place of the EMCs. Up to fourteen constituents are represented in the table. Loads are calculated by multiplying CVOL by EMC from table I.1.

Table I.1. Summary of Event Mean Concentration Data by Event

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	EVENT MEAN CONCENTRATIONS TSS	TDS	SO4	CL2	NH4	NO3	K-N	P	COD	PB	CU	FE	MN	PH	SC
		IN	MIN	IN	IN	CFS	CFS	FT3	FT3	----------------------------MGL----------------------------														UMHO
0/0/-2		-2		-2	-2	-1	-1	3	3	0	0	0	-1	-2	-1	-1	-2	0	-2	-3	-2	-2	-1	0
101781	1	24	42	34	252	798	818	833																
836	2	25	35	42	240	225	427	257	259	169	232	33	160										73	317
1102	3					1253	2044	1400	1441	191	214	47	201										73	384
	4	23	28	49	216	917	1438	1009																
	5					1004	1478	1091																
101781	1	45	66	40	312	1490	1835	2766	2781	87	303	39	213										78	640
2050	2	33	65	30	240	206	1003	551																
33	3					1151	3784	2703																
	4																							
	5					1679	2809	4789	4867	303	342	44	193										74	516
102281	1	35	250	8	24	540	584	1083	1093	60	367			11	11		13		-4		125			
619	2	51	316	10	36	272	493	594	607	77	145	27	103	17	7	22	45	92	-9	29	150	17	75	246
200	3					703	1580	1529	1499	102	153	30	122	27	7	35	51	93	14	46	208	22	73	284
	4	53	323	10	36	1228	2050	2573	2559	104	190	34	143	21	42	29	43	89	8	-20	161	16	77	395
	5					1150	1827	3049	3006	128	322	49	265	77	53	38	92	57	-7	-11	262	17	78	528
111981	1	22	186	7	36	374	374	789																
1920	2	30	293	6	36	169	267	357																
2352	3																							
	4	27	282	5	36	459	700	968																
	5					433	687	914																
112381	1	20	232	5	60		374																	
934	2	20	244	5	60	284	332	236	241	182	218	33	165	54	12	29	64	123	-25	159	451	26	78	318
349	3					991	1123	736	733	173	247	41	197	92	12	38	62	105	-23	-83	421	29	74	371
	4	22	235	6	60		992																	
	5						380																	
112681	1	14	44	19	36	320	320	209																
1419	2	18	48	22	60	200	365	130																
299	3					543	1150	355																
	4	18	50	21	96	352	967	230																
	5					347	367	227																
113081	1	9	125	4	24	374	374	591																
1641	2	27	184	9	96	230	321	330	335	125	240	36	137										92	348
395	3					721	938	1037	1028	118	198	39	141										85	330
	4	31	190	10	120	577	942	848																
	5					417	687	1112																
31282	1	32	114	16	168	3283	3930	7627	7626	545	274	34	223	-12	112	34	49	62	-4	-18	747	59	79	515
2200	2	39	132	18	192	318	870	960	1146	2395	316	37	469	-63	-9	99	229	1076	282	-247	3025	300	75	443
158	3					562	1822	1980	2005	1354	221	33	329	34	12	55	123	571	138	214	1603	151	76	364
	4	38	131	17	180	4201	4459	9415																
	5					4394	4994	12279	12320	601	310	40	352	85	77	42	95	148	-23	-36	760	54	77	516

DATE TIME DRYDAZ	SITE	RAINFALL				DISCHARGE		RUNOFF		EVENT MEAN CONCENTRATIONS														
		TRAIN	DUR	INT	MX5	MEAN	PEAK	GVOL	CVOL	TSS	TDS	SO4	CL2	NH4	NO3	K-N	P	COD	PB	CU	FE	MN	PH	SC
31482	1	36	313	6	24	1817	1987	4057																
2103	2	26	289	5	36	323	493	721																
138	3					558	1059	1246																
	4	30	294	6	36	2594	2816	5788																
	5					2958	3244	6601																
31682	1	23	153	9	96	2834	3651	6852	6834	341	368	36	234	-11	130	23	21	73	-4	-9	279	23	76	570
48	2	21	189	7	72	311	600	761																
90	3					504	1141	1331	1249	389	352	43	343	24	21	33	45	242	49	80	528	53	76	430
	4	17	159	6	72	3456	4139	7475																
	5					3842	4152	8886	8907	182	440	47	309	66	93	23	53	44	-4	-9	230	16	76	578
31982	1	34	325	6	72	1417	1467	3111																
337	2	42	334	8	84	344	788	741	751	288	259	44	356	-9	24	11	20	54	8	-19	167	15	76	425
276	3					503	1822	1126	1231	262	264	43	286	-9	24	11	21	49	-9	-16	198	12	76	383
	4	41	329	7	72	1995	3436	4116																
	5					2195	2632	5137																
31982	1	8	70	6	60	3330	3930	5910	5945	749	316	36	306	-12	119	49	54	100	-4	19	1079	68	75	547
1706	2	10	118	5	60	268	387	487	489	174	222	39	293	39	21	23	31	113	22	24	536	28	76	391
30	3					328	665	706	729	181	202	39	266	41	22	19	28	101	20	50	414	22	76	396
	4	10	126	4	48	4005	4405	6334	6359	204	312	40	318	42	89	22	41	52	-4	-9	500	16	77	573
	5					4266	4863	8890	8870	223	309	44	328	58	89	27	71		-4	-9	565	18	76	571
40282	1	46	52	53	336	580	600	506																
2233	2	61	61	60	408	777	1589	569	606	2362	224	28	167	56	8	102	198	668	206	383	2483	237	76	234
1386	3					1805	3216	1336	1343	1792	194	24	135	33	7	78	163	459	144	221	1586	147	77	230
	4	49	65	45	264	2229	4196	1618																
	5					938	1513	2085																
41582	1	11	81	8	36	494	494	397																
2007	2	12	120	6	36	255	332	179	177	301	425	63	796	78	21	41	60	227	40	48	472	37	76	674
1281	3					190	359	145	159	187	450	71	576	68	23	38	55	146	29	70	308	29	75	686
	4	12	74	10	36	871	1011	621																
	5						853																	
41682	1	62	142	26	276	1339	3967	2049	3656	444	246			10	120		54		-8		241			
2022	2	66	156	25	252	566	1003	1063	1139	734	172	22	188	33	7	48	66	252	68	107	1089	95	78	233
89	3					980	1854	1971	2005	725	181	25	165	38	8	40	83	252	75	100	1061	73	78	243
	4	72	185	24	300	2295	3329	3956	4114	546	232	36	252	36	37	53	53	255	41	86	778	64	77	407
	5					1857	2893	4336	4430	826	330	55	466	153	50	56	110	124	-36	-28	1113	59	76	633
51582	1	27	26	62	156	237	237	153																
1423	2	43	22	117	228	651	1055	326	332	1250	253	32	192	29	-1	72	136	324	78	129	1039	86	73	283
830	3					1498	2846	763	792	1299	220	47	152	-34		80	176	352	-96	-473	1754	106	74	253
	4	55	21	174	312	1840	3491	920																
	5						678																	
52982	1	15	71	12	96	489	489	487	484					-9	150	17	11	24	61	-9	200	32		
936	2	38	74	30	324	482	870	384	397					-9	8	31	56	127	31	-30	390	38		
25	3					690	1514	545	553					-11	8	31	63	134	39	-41	697	43		
	4	10	68	9	48	1244	2009	837	833					-9	60	28	40	76	-14	-20	448	27		
	5						881																	

DATE																								
TIME		----RAINFALL-----				-DISCHARGE-		--RUNOFF--						EVENT MEAN CONCENTRATIONS										
DRYDAZ	SITE	TRAIN	DUR	INT	MX5	MEAN	PEAK	GVOL	CVOL	TSS	TDS	SO4	CL2	NH4	NO3	K-N	P	COD	PB	CU	FE	MN	PH	SC
53182	1	132	470	16	132	1705	2834	4783	4824	2515	365	31	174										76	436
1550	2	158	367	26	312	630	1041	1779	1746	499	153	14	62										78	146
189	3					1596	4186	4527	4318	295	132	14	56										76	162
	4	162	284	34	204	4860	6495	13516	13121	522	174	23	105										77	266
	5					4773	6828	17385	17253	789	261	27	158										73	340
61582	1					300	300	918	918	180	250			-9	150		11		61		200			
1326	2	118	264	27	516	398	2157	1228	1268	392	58	22	92	-9	13	50	62	183	45	89	242	67	79	171
1422	3					1167	6234	3739	4720	526	109	18	73	-11	7	32	57	117	-31	-84	718	43	78	186
	4	107	267	24	348	1686	6640	5187	5738	542	185	22	92	-11	26	49	65	167	33	110	887	68	80	221
	5					1941	4507	6370	6646	1040	280	35	205	166	36	53	181	105	18	60	1297	63	78	381
61882	1	32	291	6	48	299	299	593	594	68	250			10,	120		11		-4		140			
2104	2																							
274	3					755	2383	1619	1675	240	247	23	110	-10	10	21	40	77	-15	58	297	27	75	223
	4	30	301	5	156	1220	2733	2483	2504	249	208	32	164	-11	48	23	31	71	-9	-36	227	25	77	367
	5					1366	2253	3092	3102	324	372	45	296	76	67	28	156	52	-7	-17	434	28	75	530
62882	1	20	56	21	72	171	171	281	280	68	351	38	230	-9	126	8	8	20	-4	-9	141	6	82	655
1214	2	98	105	56	528	415	1948	774	868	424	122	17	62	-9	7	27	57	119	27	46	589	35	80	149
923	3					1027	5532	2099	2168	652	140	19	58	-9	7	28	55	117	33	86	547	46	81	144
	4	55	110	30	396	1279	5125	2451	2455	649	168	25	77	-9	20	-36	76	153	26	54	617	40	78	205
	5					1645	3453	3395	3413	988	287	37	187	67	32	48	178	101	-14	-44	1117	69	76	366
70282	1	240	560	26	348	610	1830																	
1849	2	286	561	31	324	1126	3115																	
400	3					2453	6552																	
	4	259	545	29	348	4389	10925																	
	5					3501	10552																	
71082	1	42	52	48	216	208	223	251																
800	2	74	52	85	348	526	1826	664																
633	3					975	3864	1419	1661	348	122	20	78	15		25	35	81	18	30	1227	29	75	190
	4	66	77	52	324	1949	5125	2447	2576	387	182	25	103	15	10	30	47	107	25	51	543	36	75	249
	5					1515	3133	2684	2770	629	284	44	227	85	37	49	132	131	15	49	1192	75	75	456
71082	1	10	30	20	60	230	237	143																
1759	2	6	23	16	36	116	136	72																
25	3					163	214	101																
	4	5	20	15	24	399	426	249																
	5					666	666	415																
71882	1								421	141	452			-9	7		16		28		498			
2139	2	114	286	24	228	406	1605	1016	1097	278	172	20	51	-9	9	21	40	109	17	69	432	28	79	168
808	3					1093	4775	3033	3052	355	123	21	54	-9	8	21	40	102	22	87	557	33	78	171
	4	146	299	29	348	3172	5788	6524	6557	741	231	19	93	-9	13	34	75	130	17	61	1310	67	77	234
	5					3988	6176	9567	9494	1300	181	28	109	-16	19	37	114	127	10	43	1743	76	75	228
80582	1																							
1456	2	110	170	38	744	881	1861	2443																
1729	3					1203	8803	3698																
	4	130	180	43	384	2709	7420	7551																
	5					2569	5239	7860																

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	TSS	TDS	SO4	CL2	NH4	NO3	EVENT MEAN CONCENTRATIONS K-N	P	COD	PB	CU	FE	MN	PH	SC
80882	1																							
121	2	27	31	52	156	208	276	188																
206	3					474	837	434																
	4	33	81	25	144	687	992	617																
	5					509	683	473																
82082	1	12	32	22	60	102	104	92	90	48	370	43	320	-9	29	11	8	18	-4	-9	98	7	78	660
1429	2																							
1244	3					434	897	488	437	313	311	43	442	66	5	65	87	435	29	139	674	57	75	480
	4	8	14	34	60	309	680	325	299	232	368	71	399	-48	5	31	80	100	-15	-26	411	32	75	679
	5					283	367	346																
82482	1	56	78	43	204	100	100	156	156	68	357			-9	18		13		-4		270			
1347	2																							
383	3					861	2307	1518	1580	285	154	26	97	53	10	50	73	223	43	147	800	69	76	198
	4	56	83	40	216	871	2175	1510	1586	515	311	48	281	-17	5	43	127	285	58	159	1296	94	76	428
	5					873	1783	1806	1853	524	406	64	399	205	26	54	359	125	16	62	713	65	76	572
90182	1	23	43	32	144	99	99	189	189	82	225			-9	6		13		-4		200			
846	2																							
200	3					1241	5116	1954	2336	478	135	14	45	-11	3	39	73	184	49	116	1110	69	81	142
	4	53	62	51	312	1421	4925	2252	2301	478	153	20	38	-13	5	36	78	189	40	89	948	63	78	176
	5					1197	2625	2607	2646	467	213	39	201	258	10	56	255	123	-19	50	997	63	76	358
91782	1	28	91	18	156	99	99	143	143	64	275	37	480	-9			7		-4		190		79	555
1923	2																							
1625	3					561	1586	896	907	275	212	32	117	-16	9	43	67	166	43	-77	859	42	73	263
	4	38	217	11	204	500	1472	787	830	299	216	38	178	-11	8	42	60	144	27	-50	791	40	75	339
	5					580	1096	1111	1123	192	384	91	569	381	36	80	396	68	6	-9	365	40	75	757

Table 1.2. Summary of Event Washoff Load Data by Event

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	TSS	TDS	SO4	CL2	EVENT TOTAL WASHOFF LOADS NH4	NO3	K-N	P	COD	PB	CU	FE	CR	MN
		IN	MIN	IN	IN	CFS	CFS	FT3	FT3	----------KILOGRAMS----------													
0/0/ 2		2		2	2	1	1	3	3														
101781	1	24	42	34	252	798	818	833															
836	2	25	35	42	240	225	427	257	259	1240	1702	242	117										
1102	3					1253	2044	1400	1441	7795	8733	1918	820										
	4	23	28	49	216	917	1438	1009															
	5					1004	1478	1091															
101781	1	45	66	40	312	1490	1835	2766	2781	6852	23864	3072	1678										
2050	2	33	65	30	240	206	1003	551															
33	3					1151	3784	2703															
	4																						
	5					1679	2809	4789	4867	41764	47139	6065	2660										
102281	1	35	250	8	24	540	584	1083	1093	1857	11360			3	34		4				39		
619	2	51	316	10	36	272	493	594	607	1324	2493	464	177	3	12	38	8	1581	1		26		3
200	3					703	1580	1529	1499	4330	6495	1274	518	11	30	149	22	3948	6	2	88		9
	4	53	323	10	36	1228	2050	2573	2559	7537	13769	2464	1036	15	304	210	31	6450	6		117		12
	5					1150	1827	3049	3006	10897	27412	4171	2256	66	451	323	78	4852	5		223		14
111981	1	22	186	7	36	374	374	789															
1920	2	30	293	6	36	169	267	357															
2352	3																						
	4	27	282	5	36	459	700	968															
	5					433	687	914															
112381	1	20	232	5	60		374																
934	2	20	244	5	60	284	332	236	241	1242	1488	225	113	4	8	20	4	839	1	1	31		2
349	3					991	1123	736	733	3591	5127	851	409	19	25	79	13	2180	4	1	87		6
	4	22	235	6	60		992																
	5						380																
112681	1	14	44	19	36	320	320	209															
1419	2	18	48	22	60	200	365	130															
299	3					543	1150	355															
	4	18	50	21	96	352	967	230															
	5					347	367	227															
113081	1	9	125	4	24	374	374	591															
1641	2	27	184	9	96	230	321	330	335	1186	2277	342	130										
395	3					721	938	1037	1028	3435	5764	1135	410										
	4	31	190	10	120	577	942	848															
	5					417	687	1112															
31282	1	32	114	16	168	3283	3930	7627	7626	117703	59175	7343	4816	25	2419	734	106	13390	8	3	1613	1	127
2200	2	39	132	18	192	318	870	960	1146	77729	10256	1201	1522	19	28	321	74	34921	92	7	982	2	97
158	3					562	1822	1980	2005	76882	12549	1874	1868	19	68	312	70	32422	78	12	910	1	86
	4	38	131	17	180	4201	4459	9415															
	5					4394	4994	12279	12320	209690	108160	13956	12281	297	2687	1465	331	51638	79	12	2652	4	188

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	TSS	TDS	SO4	CL2	EVENT TOTAL WASHOFF LOADS NH4	NO3	K N	P	COD	PB	CU	FE	CR	MN
31482	1	36	313	6	24	1817	1987	4057															
2103	2	26	289	5	36	323	493	721															
138	3					558	1059	1246															
	4	30	294	6	36	2594	2816	5788															
	5					2958	3244	6601															
31682	1	23	153	9	96	2834	3651	6852	6834	65997	71222	6967	4529	20	2516	445	41	14128	7	1	540	1	45
48	2	21	189	7	72	311	600	761															
90	3					504	1141	1331	1249	13760	12451	1521	1213	8	74	117	16	8560	17	3	187		19
	4	17	159	6	72	3456	4139	7475															
	5					3842	4152	8886	8907	45909	110988	11856	7794	166	2346	580	134	11099	9	1	580	1	40
31982	1	34	325	6	72	1417	1467	3111															
337	2	42	334	8	84	344	788	741	751	6125	5508	936	757	1	51	23	4	1148	2		36		3
276	3					503	1822	1126	1231	9134	9204	1499	997	2	84	38	7	1708	2		69		4
	4	41	329	7	72	1995	3436	4116															
	5					2195	2632	5137															
31982	1	8	70	6	60	3330	3930	5910	5945	126103	53203	6061	5152	19	2004	825	91	16836	6	3	1817	1	114
1706	2	10	118	5	60	268	387	487	489	2410	3074	540	406	5	29	32	4	1565	3		74		4
30	3					328	665	706	729	3737	4170	805	549	8	45	39	6	2085	4	1	85		5
	4	10	126	4	48	4005	4405	6334	6359	36738	56187	7203	5727	76	1603	396	74	9365	6	1	900	1	29
	5					4266	4863	8890	8870	56017	77620	11053	8239	146	2236	678	178		9	1	1419	1	45
40282	1	46	52	53	336	580	600	506															
2233	2	61	61	60	408	777	1589	569	606	40536	3844	481	287	10	14	175	34	11464	35	7	426	2	41
1386	3					1805	3216	1336	1343	68156	7379	913	513	13	27	297	62	17457	55	8	503	2	56
	4	49	65	45	264	2229	4196	1618															
	5					938	1513	2085															
41582	1	11	81	8	36	494	494	397															
2007	2	12	120	6	36	255	332	179	177	1509	2130	316	399	4	11	21	3	1138	2		24		2
1281	3					190	359	145	159	842	2026	320	259	3	10	17	2	657	1		14		1
	4	12	74	10	36	871	1011	621															
	5						853																
41682	1	62	142	26	276	1339	3967	2049	3656	45971	25470			10	1242		56		7		250		
2022	2	66	156	25	252	566	1003	1063	1139	23676	5548	710	606	11	23	155	21	8129	22	3	351		31
89	3					980	1854	1971	2005	41167	10277	1420	937	22	45	227	47	14309	43	6	602	1	41
	4	72	185	24	300	2295	3329	3956	4114	63614	27030	4194	2936	42	431	617	62	29710	48	10	906	3	75
	5					1857	2893	4336	4430	103628	41401	6900	5846	192	627	703	138	15557	44	3	1396	1	74
51582	1	27	26	62	156	237	237	153															
1423	2	43	22	117	228	651	1055	326	332	11753	2379	301	181	3		68	13	3046	7	1	98		8
830	3					1498	2846	763	792	29136	4934	1054	341	7		179	39	7895	21	10	393	2	24
	4	55	21	174	312	1840	3491	920															
	5						678																
52982	1	15	71	12	96	489	489	487	484						206	23	1	329	8		27		4
936	2	38	74	30	324	482	870	384	397						9	35	6	1428	3		44		4
25	3					690	1514	545	553					1	13	49	10	2099	6		109		7
	4	10	68	9	48	1244	2009	837	833					1	142	66	9	1793	2		106		6
	5						881																

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	TSS	TDS	SO4	CL2	EVENT TOTAL WASHOFF LOADS NH4	NO3	K N	P	COD	PB	CU	FE	CR	MN
53182	1	132	470	16	132	1705	2834	4783	4824	343588	49865	4235	2377										
1550	2	158	367	26	312	630	1041	1779	1746	24674	7565	692	307										
189	3					1596	4186	4527	4318	36074	16142	1712	685										
	4	162	284	34	204	4860	6495	13516	13121	193968	64656	8546	3902										
	5					4773	6828	17385	17253	385509	127526	13192	7720										
61582	1					300	300	918	918	4680	6499			1	390		3		16		52		
1326	2	118	264	27	516	398	2157	1228	1268	14077	2083	790	330	2	47	180	22	6571	16	3	87		24
1422	3					1167	6234	3739	4720	70311	14570	2406	976	14	94	428	76	15639	40	10	960	2	57
	4	107	267	24	348	1686	6640	5187	5738	88075	30063	3575	1495	17	422	796	106	27138	54	18	1441	6	110
	5					1941	4507	6370	6646	195743	52700	6588	3858	312	678	998	341	19763	34	11	2441	7	119
61882	1	32	291	6	48	299	299	593	594	1144	4206			2	202		2				24		
2104	2																						
274	3					755	2383	1619	1675	11385	11717	1091	522	4	47	100	19	3653	6	3	141		13
	4	30	301	5	156	1220	2733	2483	2504	17657	14750	2269	1163	7	340	163	22	5035	5	2	161		18
	5					1366	2253	3092	3102	28463	32680	3953	2600	67	589	246	137	4568	5	1	381	1	25
62882	1	20	56	21	72	171	171	281	280	539	2783	301	182		100	6	1	159			11		
1214	2	98	105	56	528	415	1948	774	868	10423	2999	418	152	1	17	66	14	2925	7	1	145		9
923	3					1027	5532	2099	2168	40031	8596	1167	356	5	43	172	34	7184	20	5	336		28
	4	55	110	30	396	1279	5125	2451	2455	45122	11680	1738	535	5	139	249	53	10637	18	4	429	1	28
	5					1645	3453	3395	3413	95496	27740	3576	1807	65	309	464	172	9762	13	3	1080	2	67
70282	1	240	560	26	348	610	1830																
1849	2	286	561	31	324	1126	3115																
400	3					2453	6552																
	4	259	545	29	348	4389	10925																
	5					3501	10552																
71082	1	42	52	48	216	208	223	251															
800	2	74	52	85	348	526	1826	664															
633	3					975	3864	1419	1661	16370	5739	941	367	7		118	16	3810	8	1	577		14
	4	66	77	52	324	1949	5125	2447	2576	28233	13277	1824	751	11	73	219	34	7806	18	4	396		26
	5					1515	3133	2684	2770	49343	22279	3452	1781	67	290	384	104	10276	12	4	935	4	59
71082	1	10	30	20	60	230	237	143															
1759	2	6	23	16	36	116	136	72															
25	3					163	214	101															
	4	5	20	15	24	399	426	249															
	5					666	666	415															
71882	1								421	1681	5389				8		2		3		59		
2139	2	114	286	24	228	406	1605	1016	1097	8637	5344	621	158	2	28	65	12	3386	5	2	134		9
808	3					1093	4775	3033	3052	30684	10631	1815	467	7	69	181	35	8816	19	8	481		29
	4	146	299	29	348	3172	5788	6524	6557	137599	42895	3528	1727	16	241	631	139	24140	32	11	2433	3	124
	5					3988	6176	9567	9494	349531	48665	7528	2931	42	511	995	307	34146	27	12	4686	5	204
80582	1																						
1456	2	110	170	38	744	881	1861	2443															
1729	3					1203	8803	3698															
	4	130	180	43	384	2709	7420	7551															
	5					2569	5239	7860															

DATE TIME DRYDAZ	SITE	----RAINFALL----- TRAIN	DUR	INT	MX5	-DISCHARGE- MEAN	PEAK	--RUNOFF-- GVOL	CVOL	TSS	TDS	SO4	CL2	EVENT TOTAL WASHOFF LOADS NH4	NO3	K N	P	COD	PB	CU	FE	CR	MN
80882	1																						
121	2	27	31	52	156	208	276	188															
206	3					474	837	434															
	4	33	81	25	144	687	992	617															
	5					509	683	473															
82082	1	12	32	22	60	102	104	92	90	122	943	110	82		7	3		46			2		
1429	2																						
1244	3					434	897	488	437	3874	3849	532	547	8	6	80	11	5383	4	2	83	2	7
	4	8	14	34	60	309	680	325	299	1964	3116	601	338	3	4	26	7	847			35	1	3
	5					283	367	346															
82482	1	56	78	43	204	100	100	156	156	300	1577				8		1				12		
1347	2																						
383	3					861	2307	1518	1580	12752	6891	1163	434	24	45	224	33	9978	19	7	358	1	31
	4	56	83	40	216	871	2175	1510	1586	23131	13969	2156	1262	7	22	193	57	12801	26	7	582	5	42
	5					873	1783	1806	1853	27498	21306	3359	2094	108	136	283	188	6560	8	3	374	2	34
90182	1	23	43	32	144	99	99	189	189	439	1204				3		1				11		
846	2																						
200	3					1241	5116	1954	2336	31622	8931	926	298	6	20	258	48	12173	32	8	734	5	46
	4	53	62	51	312	1421	4925	2252	2301	31149	9970	1303	248	7	33	235	51	12316	26	6	618	4	41
	5					1197	2625	2607	2646	34995	15961	2922	1506	193	75	420	191	9217	13	4	747	4	47
91782	1	28	91	18	156	99	99	143	143	259	1114	150	194								8		
1923	2																						
1625	3					561	1586	896	907	7064	5445	822	301	3	23	110	17	4264	11	1	221	3	11
	4	38	217	11	204	500	1472	787	830	7028	5077	893	418	2	19	99	14	3385	6		186	3	9
	5					580	1096	1111	1123	6106	12212	2894	1810	121	114	254	126	2163	2		116	2	13

APPENDIX II

MICRO-BASIN DATA SUMMARY 1980-81

The final report on the street sweeping evaluation project included for the micro-basin, site 3, only the event data summary tables (in the supplement); analyses of that data and of the street dirt data collected there were omitted. This appendix contains the log-normal distribution plots for EMCs of nine constituents at site 3. There are also graphical presentations of the street dirt results from the basin which are similar to those given in the earlier report for the four major basins.

There were 74 events monitored on the micro-basin. The total is less than that for the major basins for two reasons. The first is that due to local variation in rainfall, occasionally there was no runoff or sampling at the micro-basin even while there was enough runoff for sampling at the larger basins. The second is that monitoring and sampling equipment was sometimes moved from the site to one of the major sites when equipment there had failed. The collection of data from the micro-basin was considered secondary in importance to the maintenance of operations at the four major sites.

Of the 74 events monitored, 44 occurred during the period of no street sweeping on the basin and 30 during the period of once-weekly sweeping. However, many of the events did not have enough water quality sample results to permit the calculation of EMCs or loads of the constituents. Only 14 to 32 events (depending on the constituent in question) had sufficient water quality data for EMC determinations. Since the EMC data sets were already very small, no further separation into subsets based on sweeping practice was feasible. Instead, the EMCs for a given constituent from all events were lumped together regardless of sweeping condition and fitted to the log-normal distribution. The resulting distributions were assumed to be representative of the micro-basin runoff response. Plots of the distributions for mean flows, peak flows, and EMCs of TSS, TDS, lead, iron, copper, NH3-N, TKN, COD, and phosphorus follow. According to these analyses, the probabilities of runoff EMCs at the micro-basin exceeding general use water quality standards are as follows: for lead, 70 percent probability of exceeding 0.1 mg/1 standard; for iron, 50 percent, 1.0 mg/1 standard; for copper, 55 percent, 0.02 mg/1 standard; and for phosphorus, 100 percent, 0.05 mg/1 standard. The standard for phosphorus does not actually apply to the micro-basin flow, however, so its exceedance does not imply standards violation.

Street dirt data comprising load, particle size distribution, and constituent concentration by size group were collected not only on the micro-basin itself but also on a neighboring city block. While the micro-basin had a fair condition concrete surface and a relatively steep slope, the other block, called Micro-basin 2, had a very good condition asphalt surface and very little slope. The loads on each of the micro-basins were determined identically and the samples kept separate for size distribution and constituent determination. The results of the monitoring effort on these two spots are given graphically in the following figures.

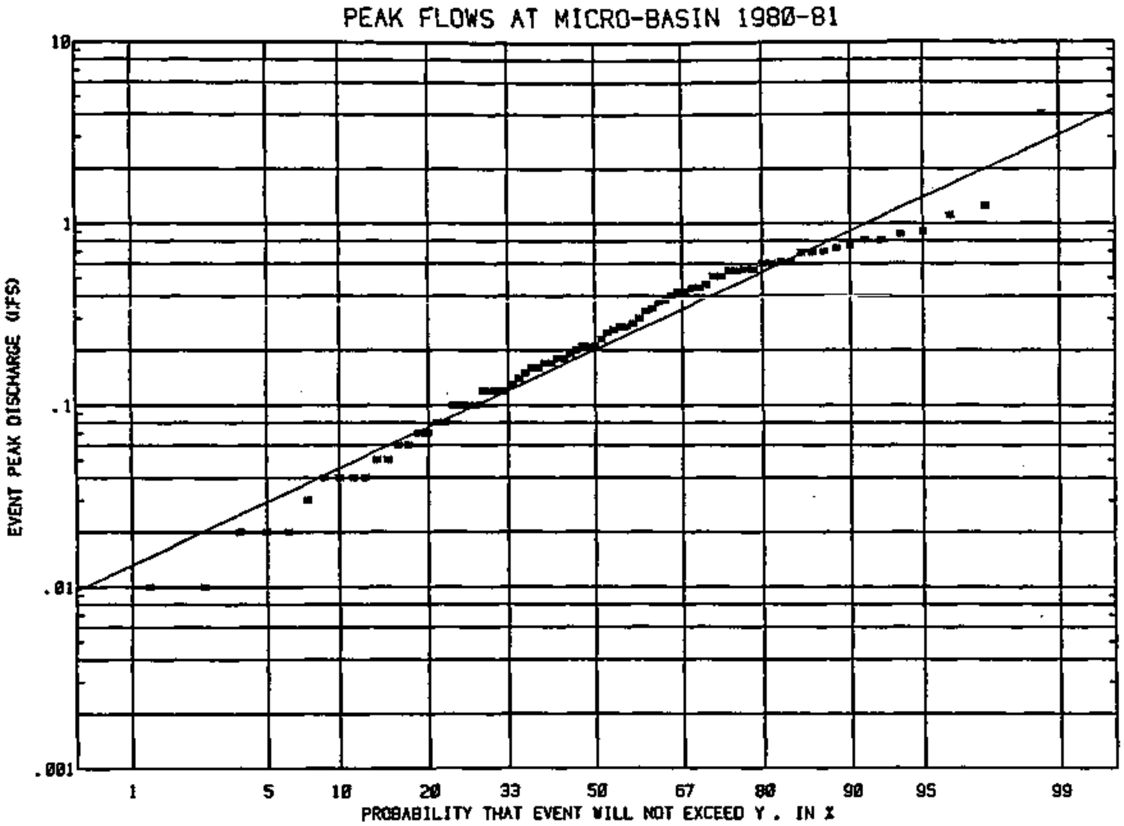
The first shows the results of total load monitoring on the two basins during the two years. The total loads are similar in magnitude throughout, but the day-to-day variability in load was high for both. The partial loads smaller than 250µ varied similarly to the total loads. The variability was due not only to wet and dry weather influences on loads, but also to intrinsic unevenness of load distribution on any city block. With areas as small as these were, small numbers of samples may not represent the actual load well due to local variability of material accumulation, a problem offset in the major basins by the taking of subsamples at many sites. However, the taking of many subsamples in the micro-basins would have had the effect of removing a significant part of the total load, so the remaining load would not have been describable by the results of sampling. Street sweeping was done once on the micro-basins in 1980, at the end of September; while both showed the immediate effects of the cleanup, the second basin remained relatively clean through October, while the first became heavily loaded again, mostly with leaves and grass, almost instantly. In 1981 once-weekly sweeping was started on both basins June 1. A curious result was that the load on Micro-basin 2 became steady at first, then progressively more variable after mid-July, while the reverse was true for Micro-basin 1.

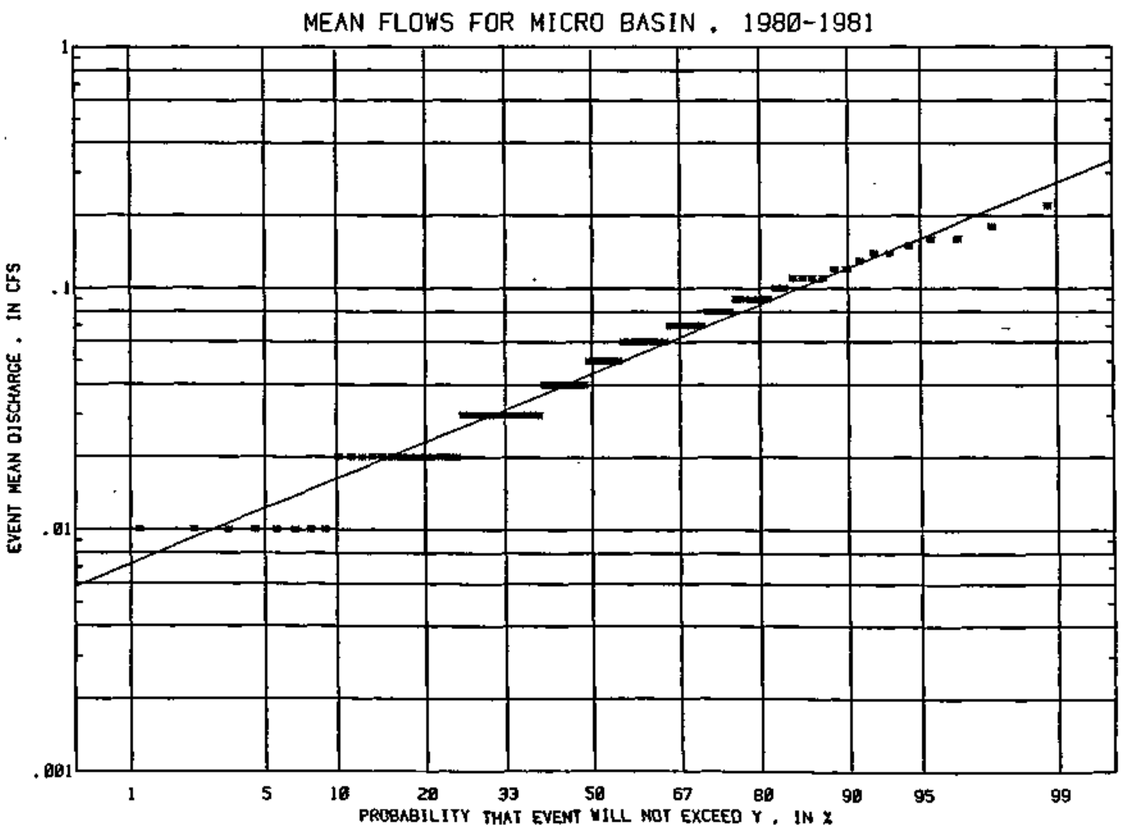
The second figure shows deposition and accumulation of street load on the two micro-basins against time. For Micro-basin 1, the initial load is 20 g/curb-m, the deposition rate is 11 g/curb-m/day, and the maximum load of 57 g/curb-m is reached 8 days after cleaning. For Micro-basin 2 the corresponding numbers are 24 g/curb-m initial, 9 g/curb-m/day, and 49 g/curb-m maximum load in 7 days. Both showed greater initial loads, similar maximum loads, higher deposition rates, and fewer days to maximum load than the John South basin of which they were part.

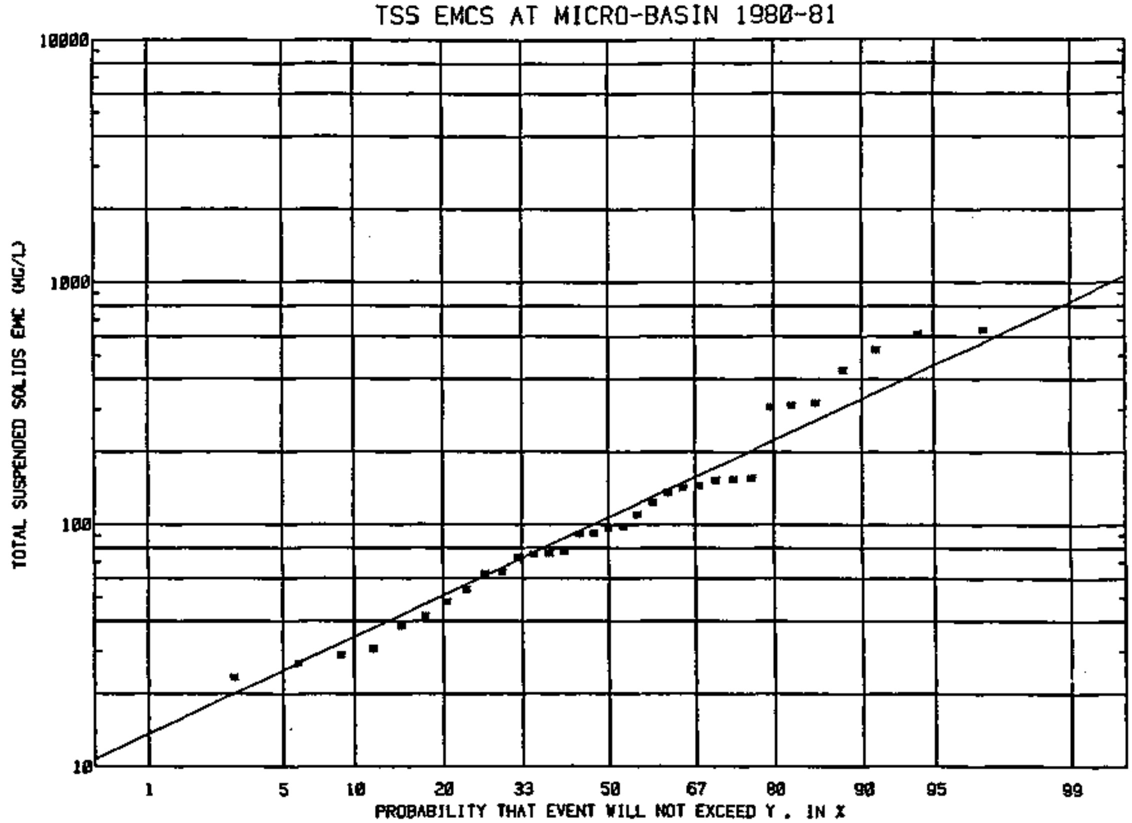
The third figure contains bar diagrams of the characteristic particle size distributions of street loads in each basin. Both the averages and the ranges of percentages of the total load found in each size group for all samples on the basin are shown. The difference between the characteristic distributions is pronounced. Micro-basin 1 has a high fraction of coarse material consistent with its street surface type and condition; the median particle size of the mean distribution is 1200µ. In comparison, Micro-basin 2 shows a more balanced distribution, with the greatest part of the material in the range of 125-1000yand only a modest fraction of coarse material. This too is fitting for an asphalt street in very good condition. The median particle size of the mean distribution for Micro-basin 2 is 410μ. The size distribution in Micro-basin 1 is much more like that of the John South basin than is the distribution in Micro-basin 2.

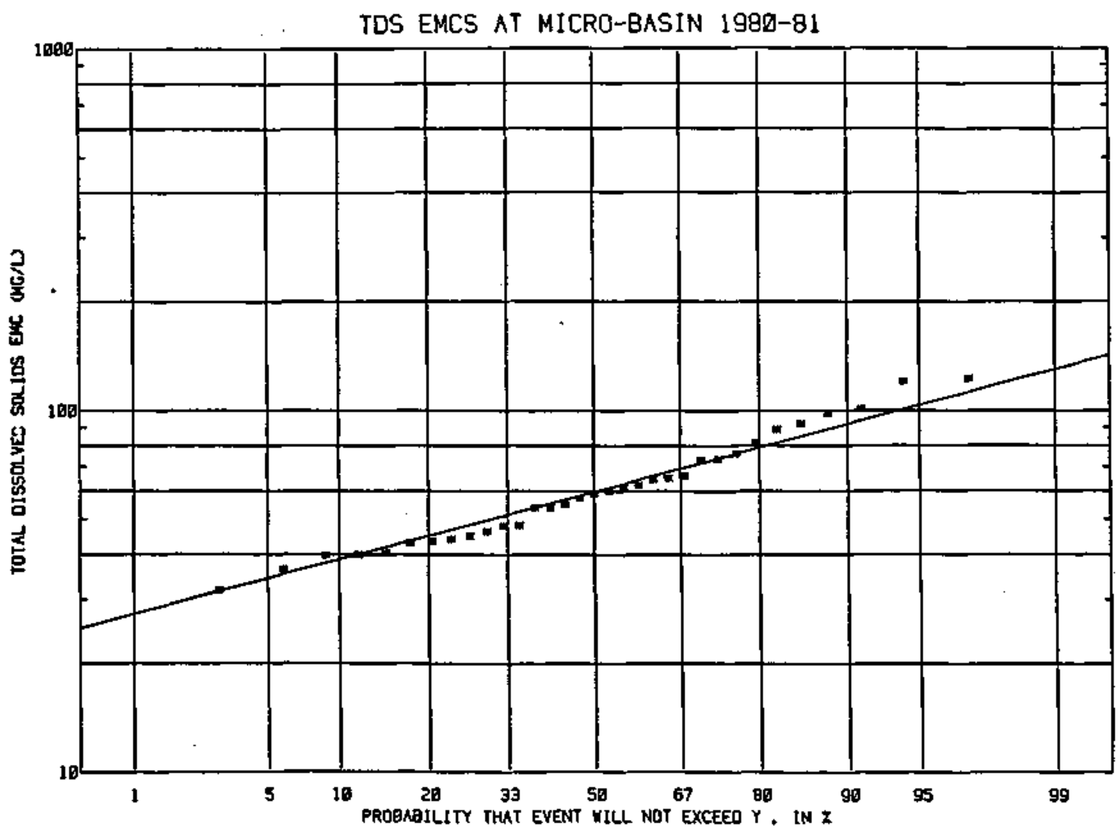
The next three figures give quality data for street loads of six constituents in each basin. The diagrams represent concentrations of lead, iron, NH3-N, TKN, phosphorus, and COD by size group. The values presented in the figures may be multiplied by an estimate of the total street load on the micro-basin and the characteristic fractions of the total load in the different size groups to produce estimates of the partial loads of the constituent on the basin in the five smaller size groups. These estimates may be added to yield an estimate of the total constituent load in material smaller than 1000μ. As the figures show, the concentrations of a constituent vary between different particle size groups at a site and between the same particle size groups at different sites. Furthermore, the relationships between concentrations in the different particle size groups at one site differ with each constituent. Generally, the largest portion of the constituent load is found in particles of size range 63-250μ. It is noteworthy that, except for iron, the constituent concentrations are higher in Micro-basin 1 than in Micro-basin 2; however, for both basins the levels of all constituents are similar to those reported for the John South basin.

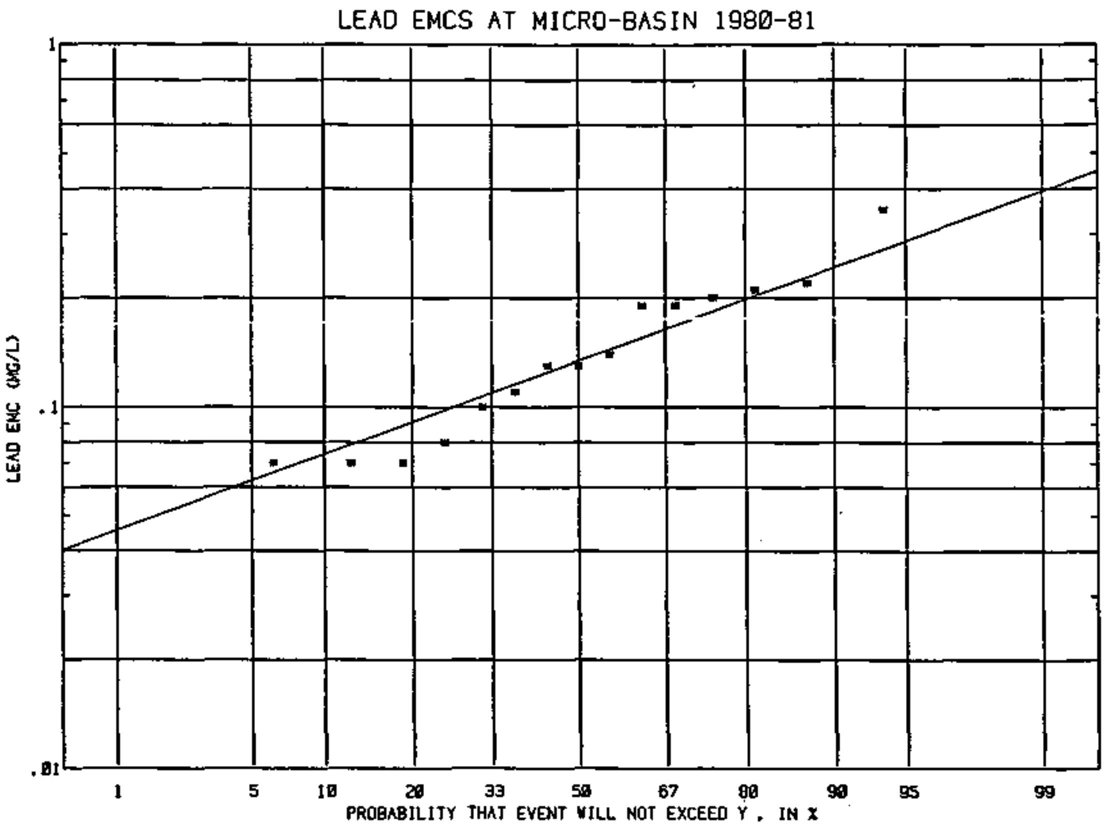
The last figure displays results of sweeper performance tests. For all days on which street load measurement was done on the micro-basins before and after sweeping, points were plotted identifying the initial basin load and the corresponding remaining load. Individual plots were generated for each of the particle size groups and for the total load. Three of these are reproduced in the figure: total load, load range 500-1000μ, and load range 125-250μ. In these plots, good sweeper performance is indicated by a low intercept and flat slope of the regression line describing the points. In the first two cases there is little difference in sweeper performance, though the load reductions appear to be slightly better for Micro-basin 1. The difference in the third group, 125-250μ, is more marked, with the sweeper performance on Micro-basin 1 much better than on Micro-basin 2. As was stated in the previous report, however, the relative performance of the street sweeper in removing solids of various sizes and the pollutants associated with them becomes insignificant when no improvement in runoff quality from a swept basin is noticeable. The event results indicate that the solids and pollutants controlled by street sweeping and carried by storm runoff constitute separate parts of the entire street load. From the standpoint of water quality improvement, then, sweeping production functions and cost functions are pointless exercises.

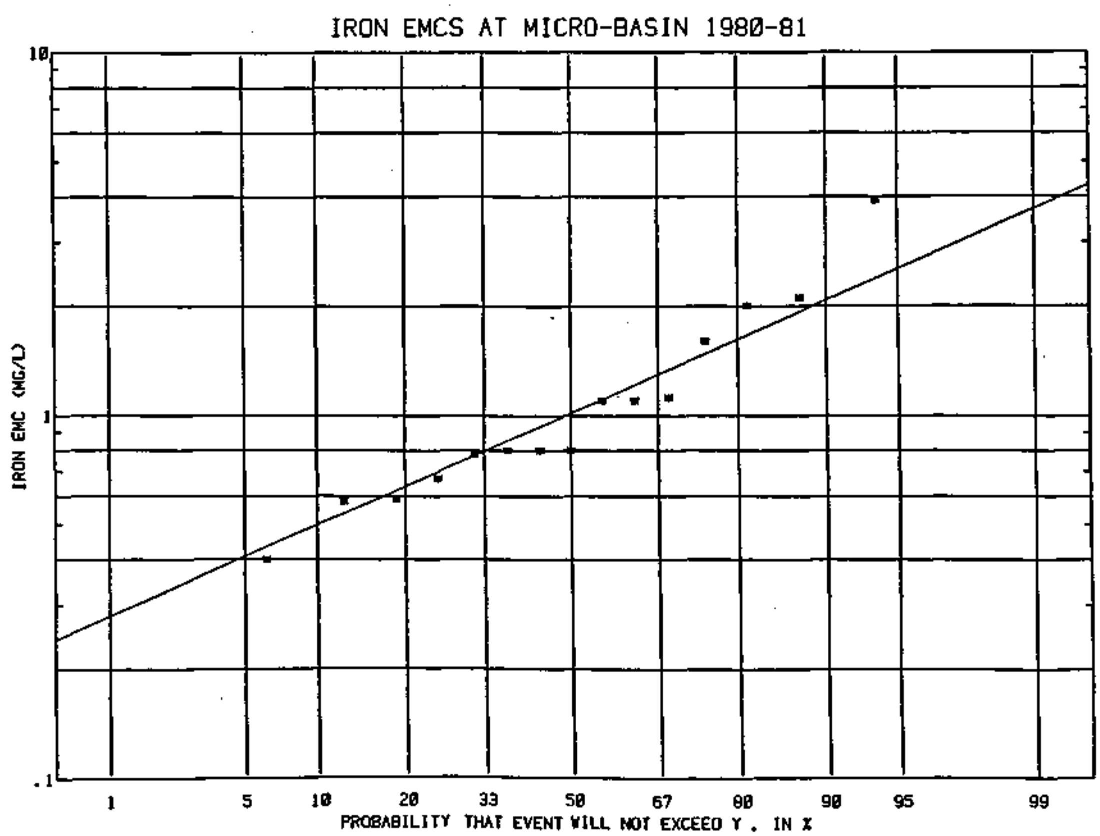

PEAK FLOWS AT MICRO-BASIN 1980-81
EVENT PEAK DISCHARGE (CFS)
10
1
.1
.01
.001
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

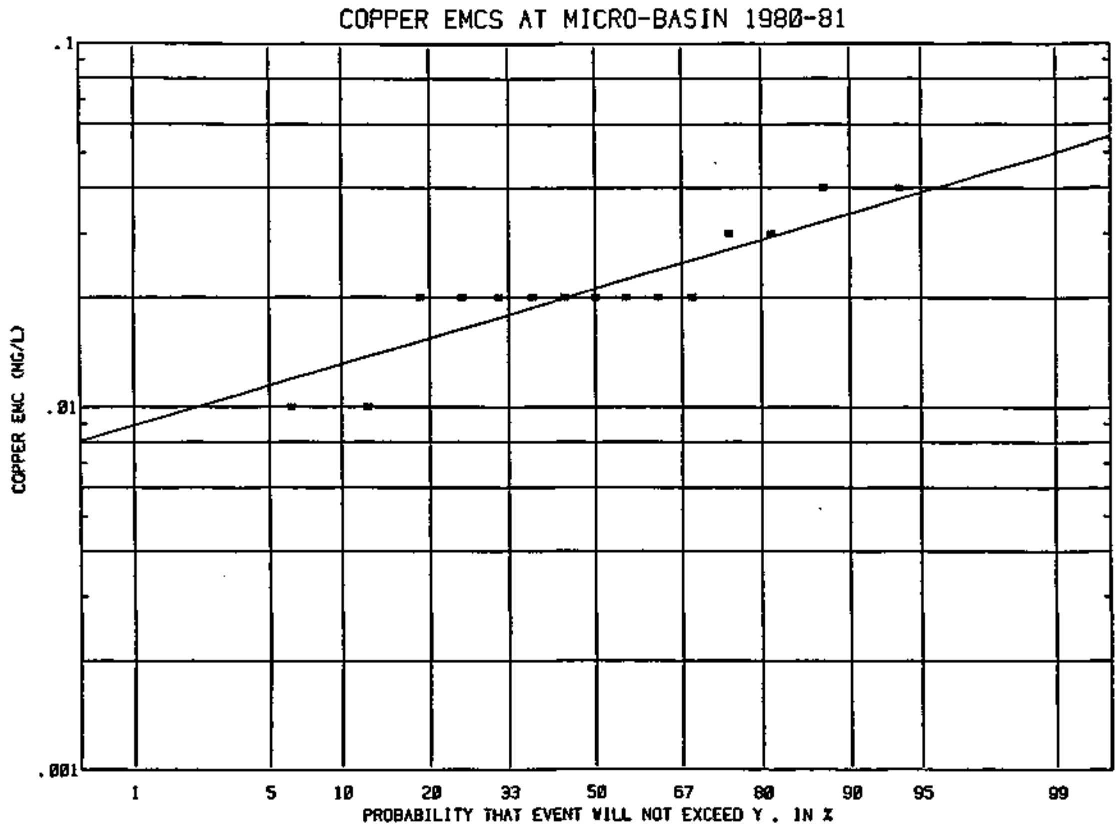

MEAN FLOWS FOR MICRO BASIN , 1980-1981
EVENT MEAN DISCHARGE , IN CFS
1
.1
.01
.001
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

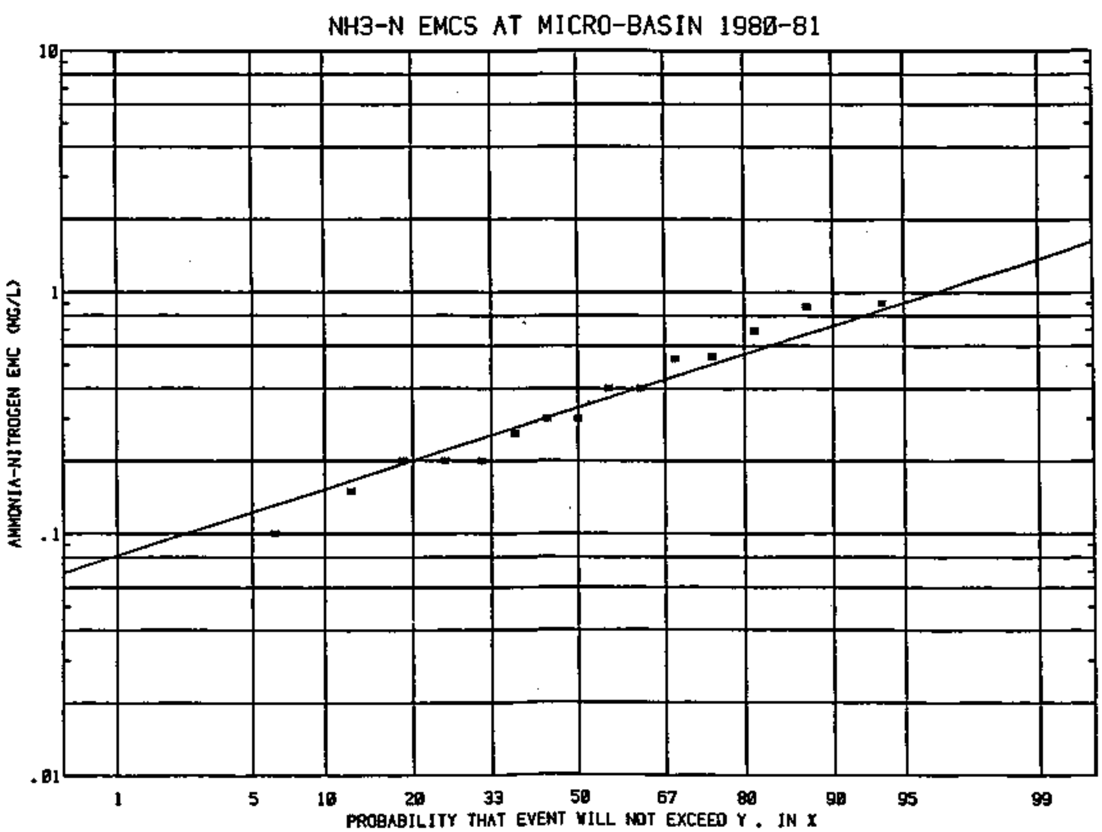

TSS EMCS AT MICRO-BASIN 1980-81
TOTAL SUSPENDED SOLIDS EMC (MG/L)
10000
1000
100
10
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y, IN %

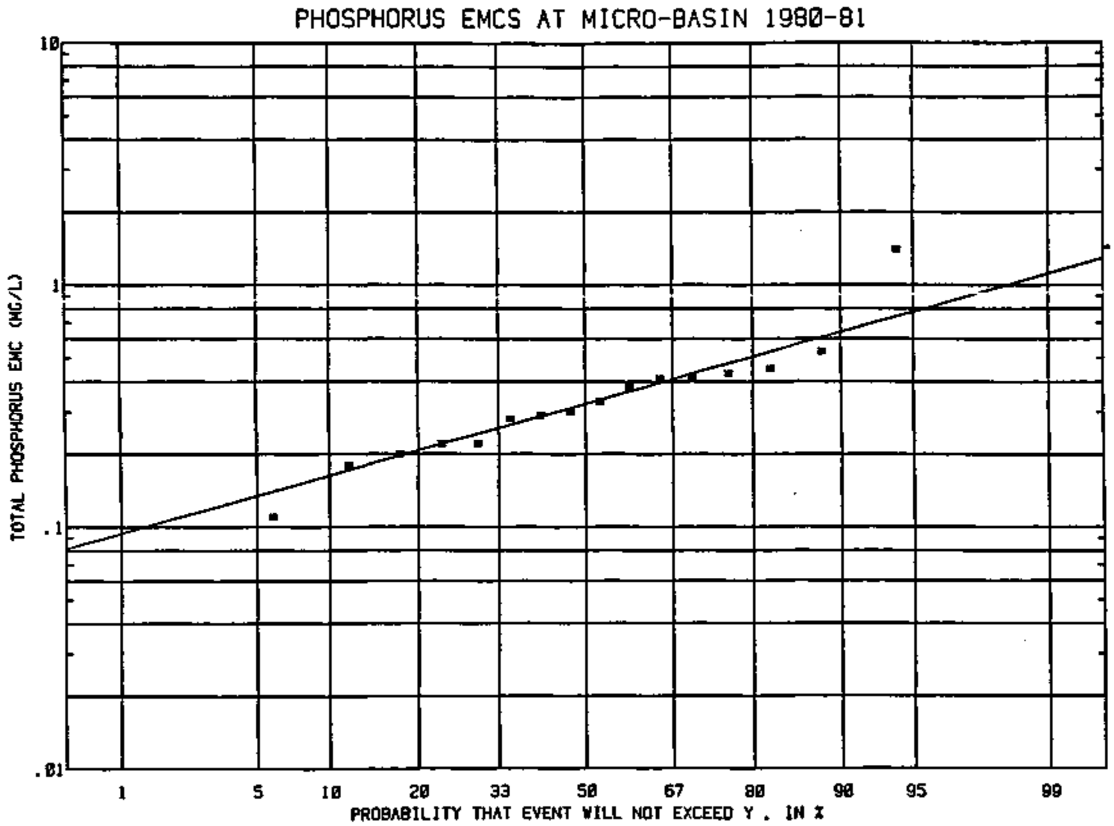

TDS EMCS AT MICRO-BASIN 1980-81
TOTAL DISSOLVED SOLIDS EMC (MG/L)
1000
100
10
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y, IN %

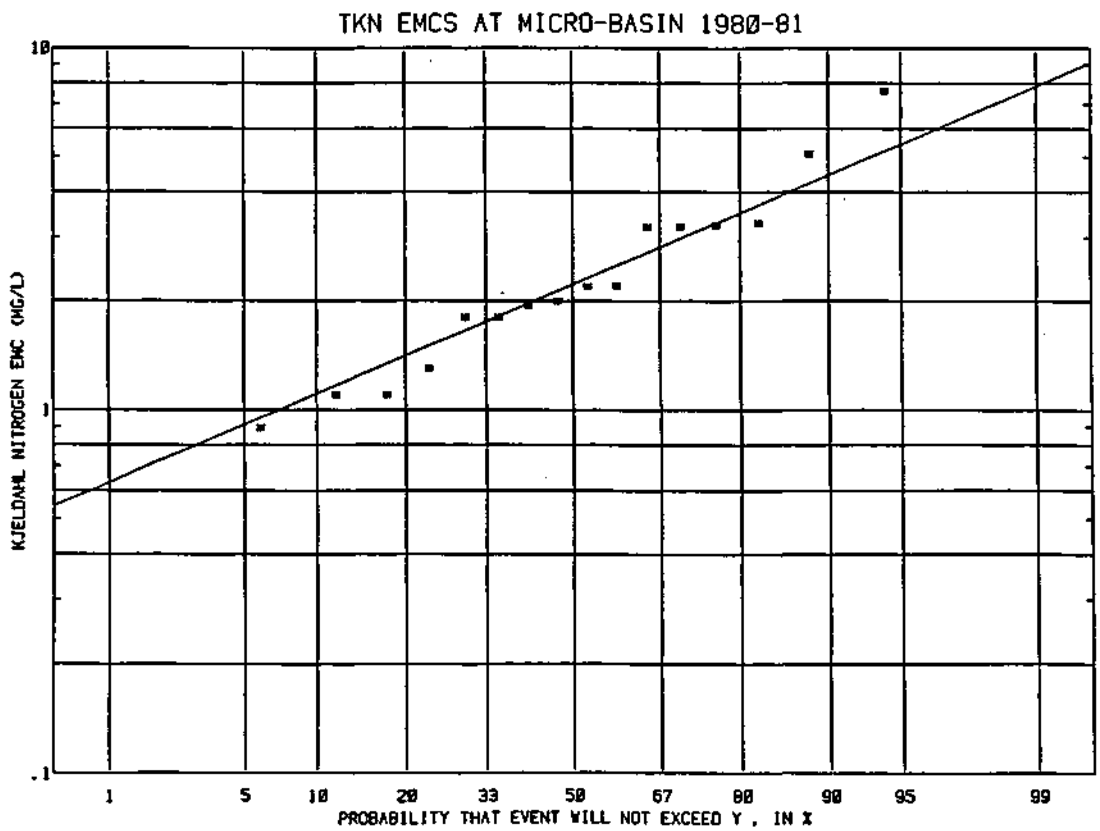

LEAD EMCS AT MICRO-BASIN 1980-81
LEAD EMC (MG/L)
1
.1
.01
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

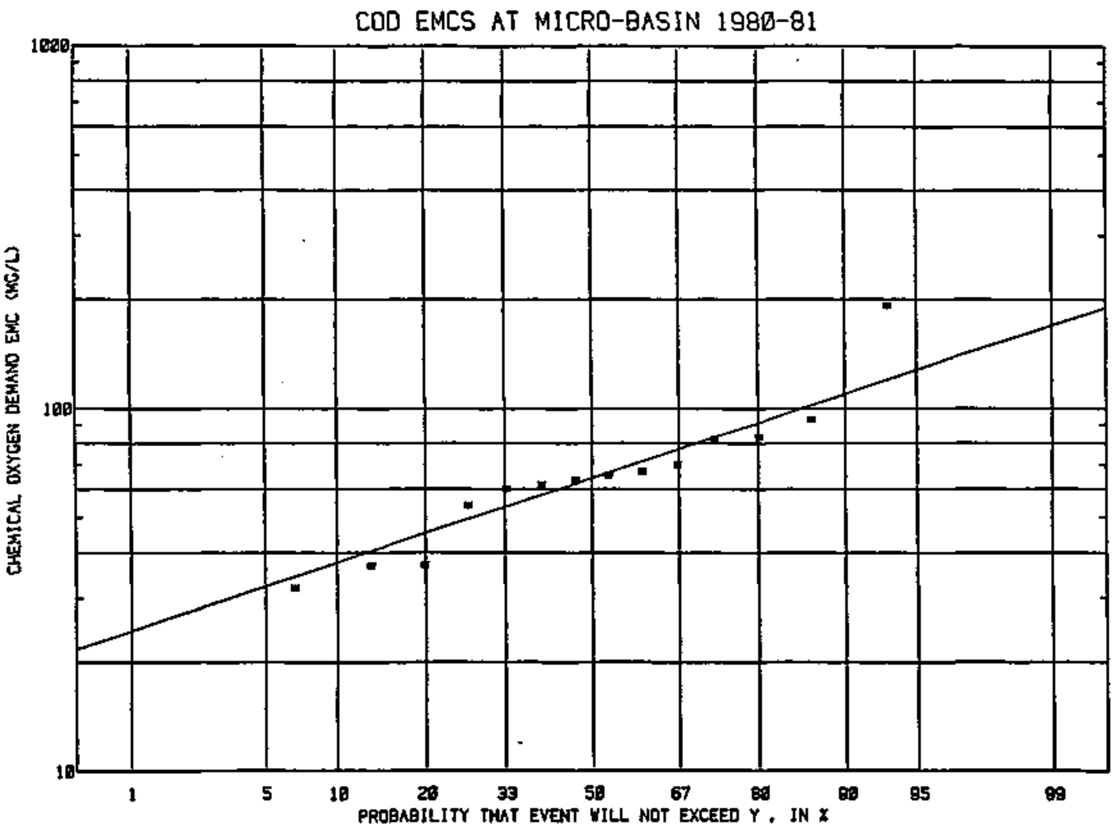

IRON EMCS AT MICRO-BASIN 1980-81
IRON EMC (MG/L)
10
1
.1
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

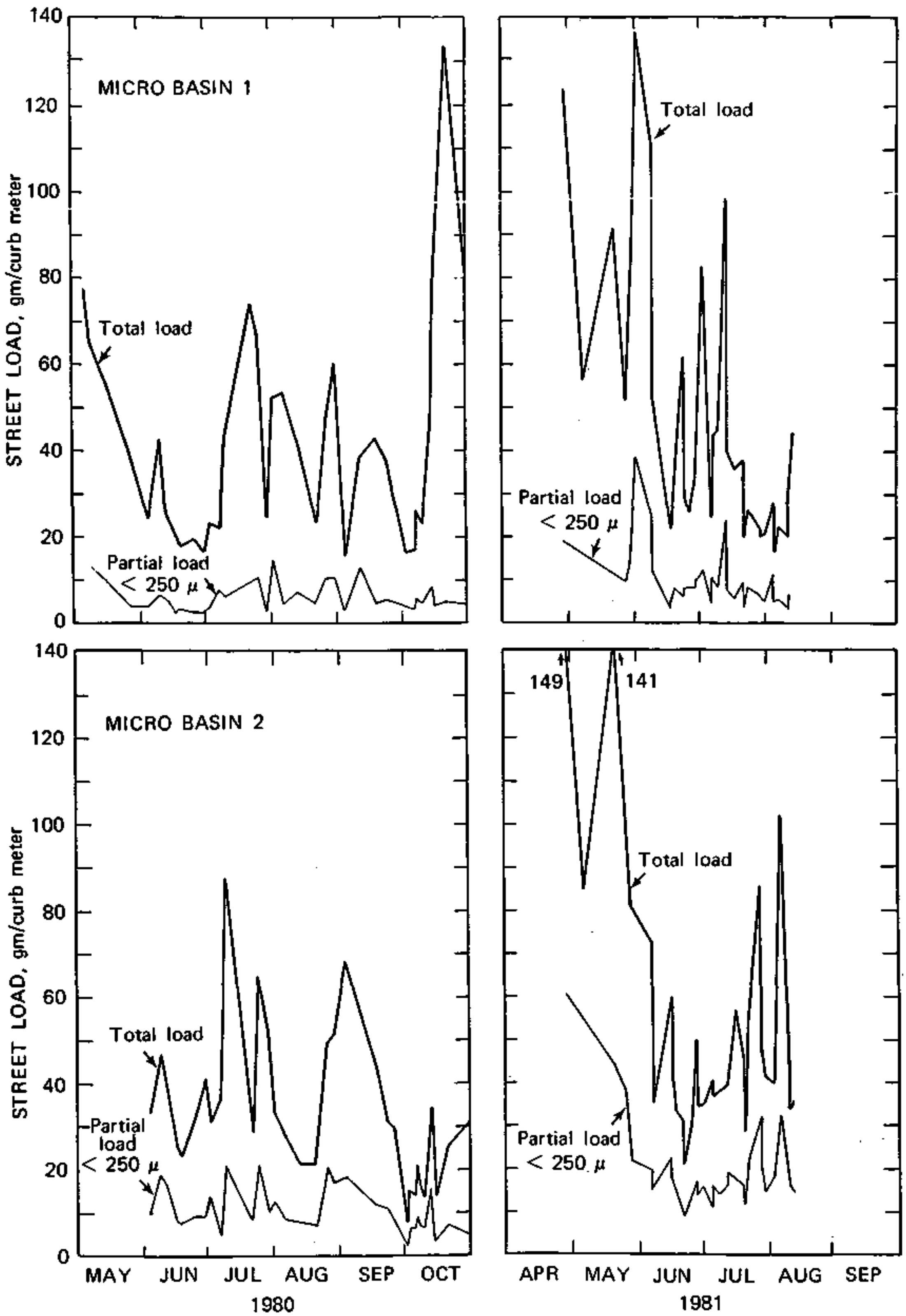

COPPER EMCS AT MICRO-BASIN 1980-81
COPPER EMC (MG/L)
.1
.01
.001
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %


NH3-N EMCS AT MICRO-BASIN 1980-81
AMMONIA-NITROGEN EMC (MG/L)
10
1
.1
.01
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

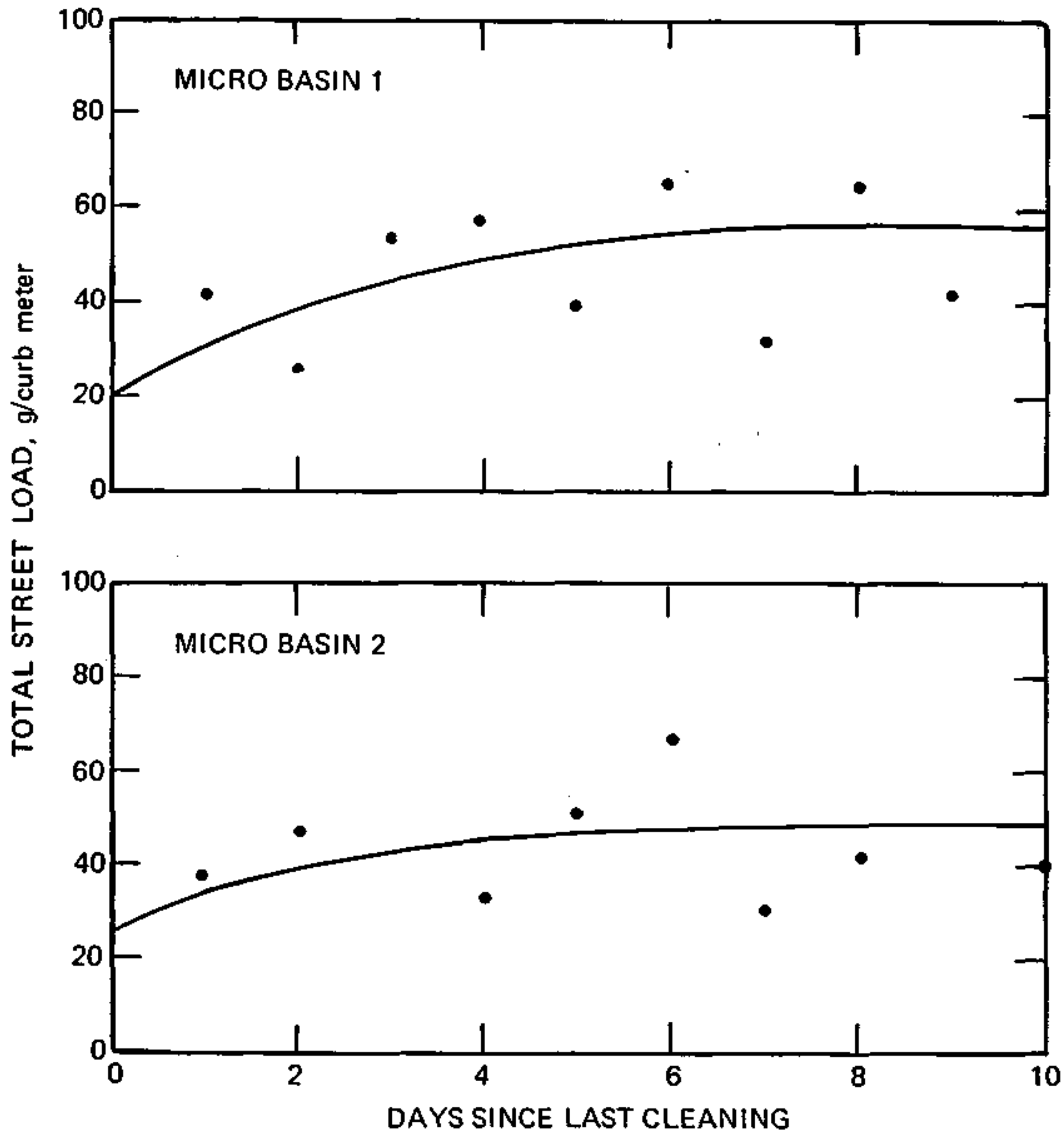

PHOSPHORUS EMCS AT MICRO-BASIN 1980-81
TOTAL PHOSPHORUS EMC (MG/L)
10
1
.1
.01
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

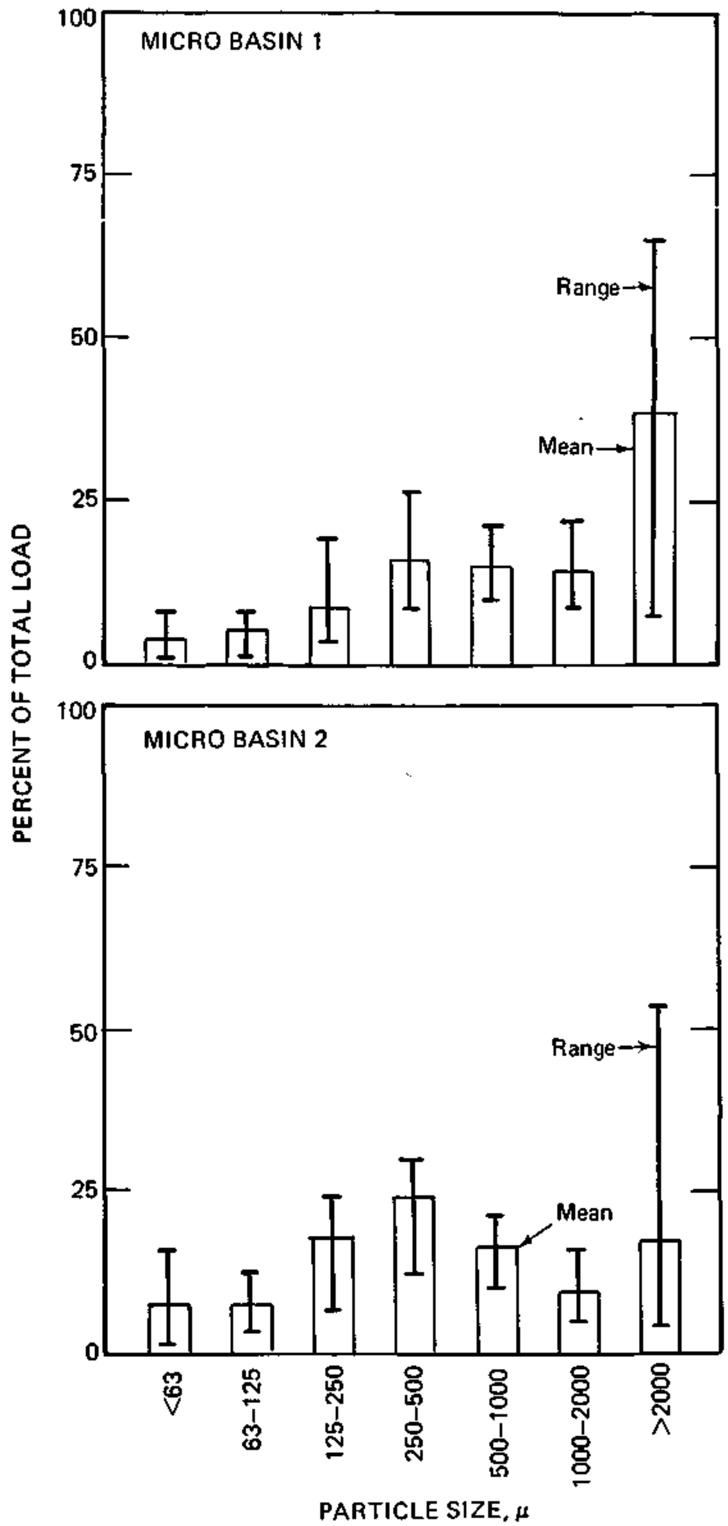

TKN EMCS AT MICRO-BASIN 1980-81
KJELDAHL NITROGEN EMC (MG/L)
10
1
.1
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

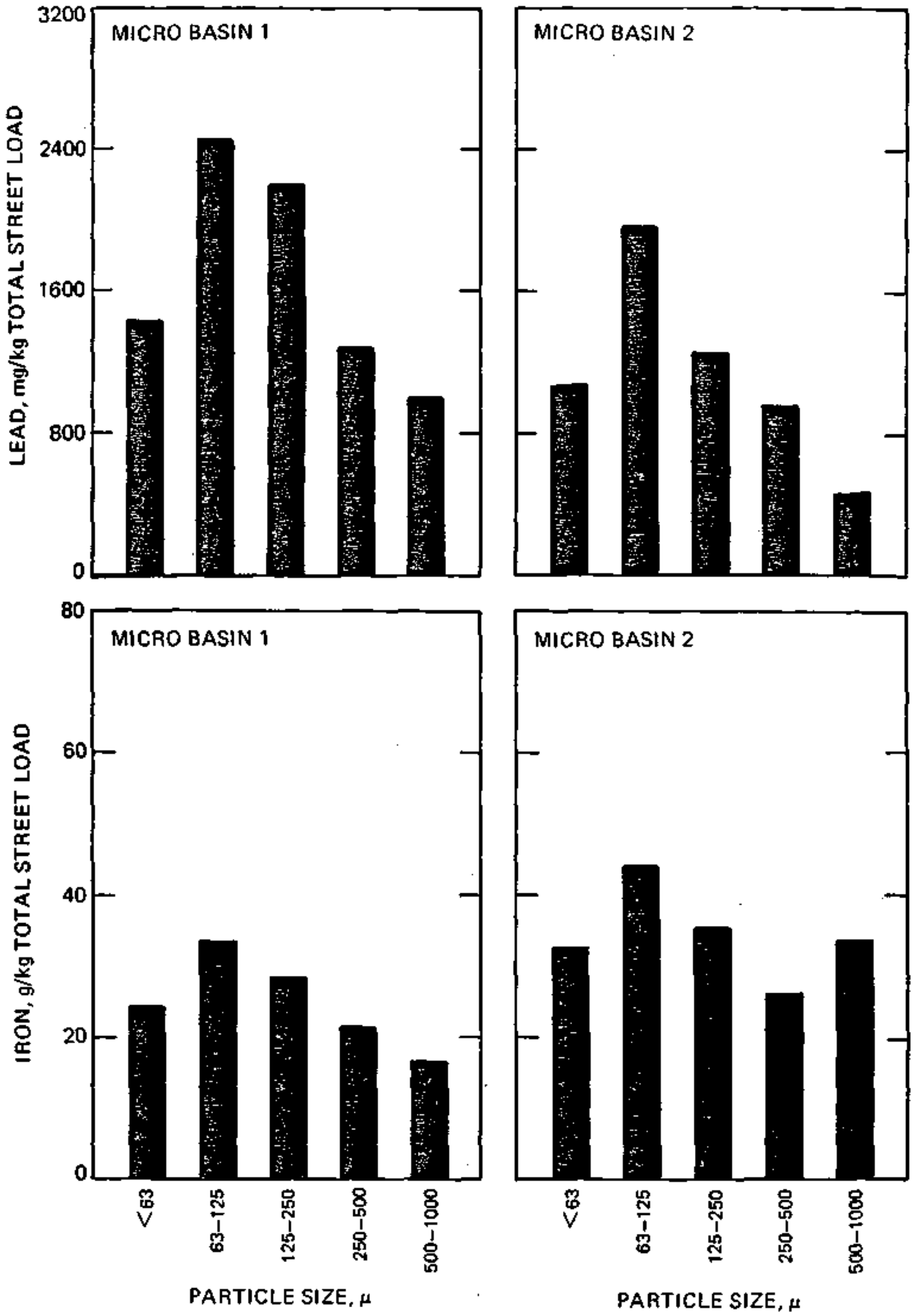

COD EMCS AT MICRO-BASIN 1980-81
1000
100
10
CHEMICAL OXYGEN DEMAND EMC (MG/L)
1
5
10
20
33
50
67
80
90
95
99
PROBABILITY THAT EVENT WILL NOT EXCEED Y , IN %

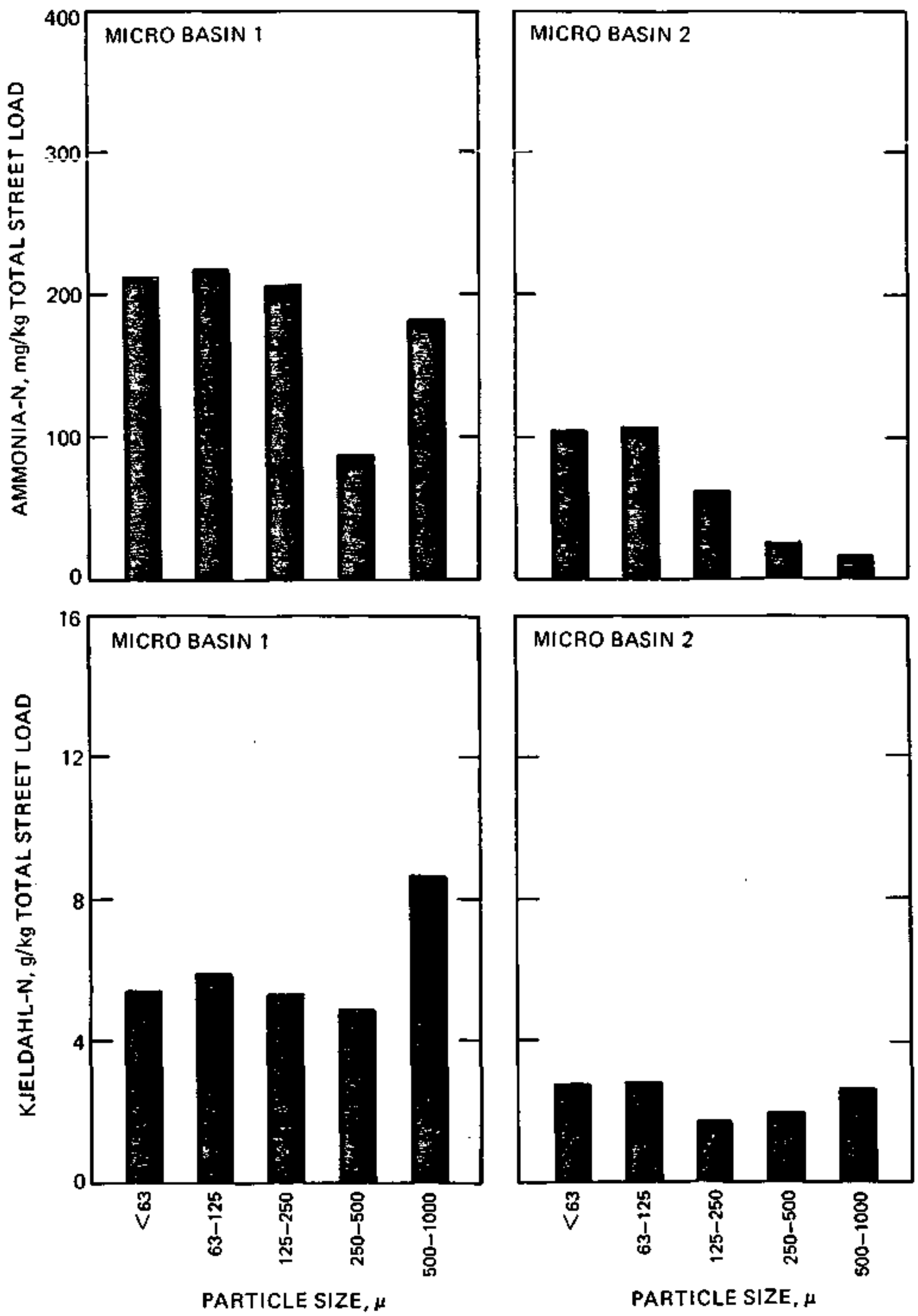


MICRO BASIN 1
MICRO BASIN 2
Total load
Partial load
< 250 μ
149
141
STREET LOAD, gm/curb meter
MAY JUN JUL AUG SEP OCT
1980
APR MAY JUN JUL AUG SEP
1981

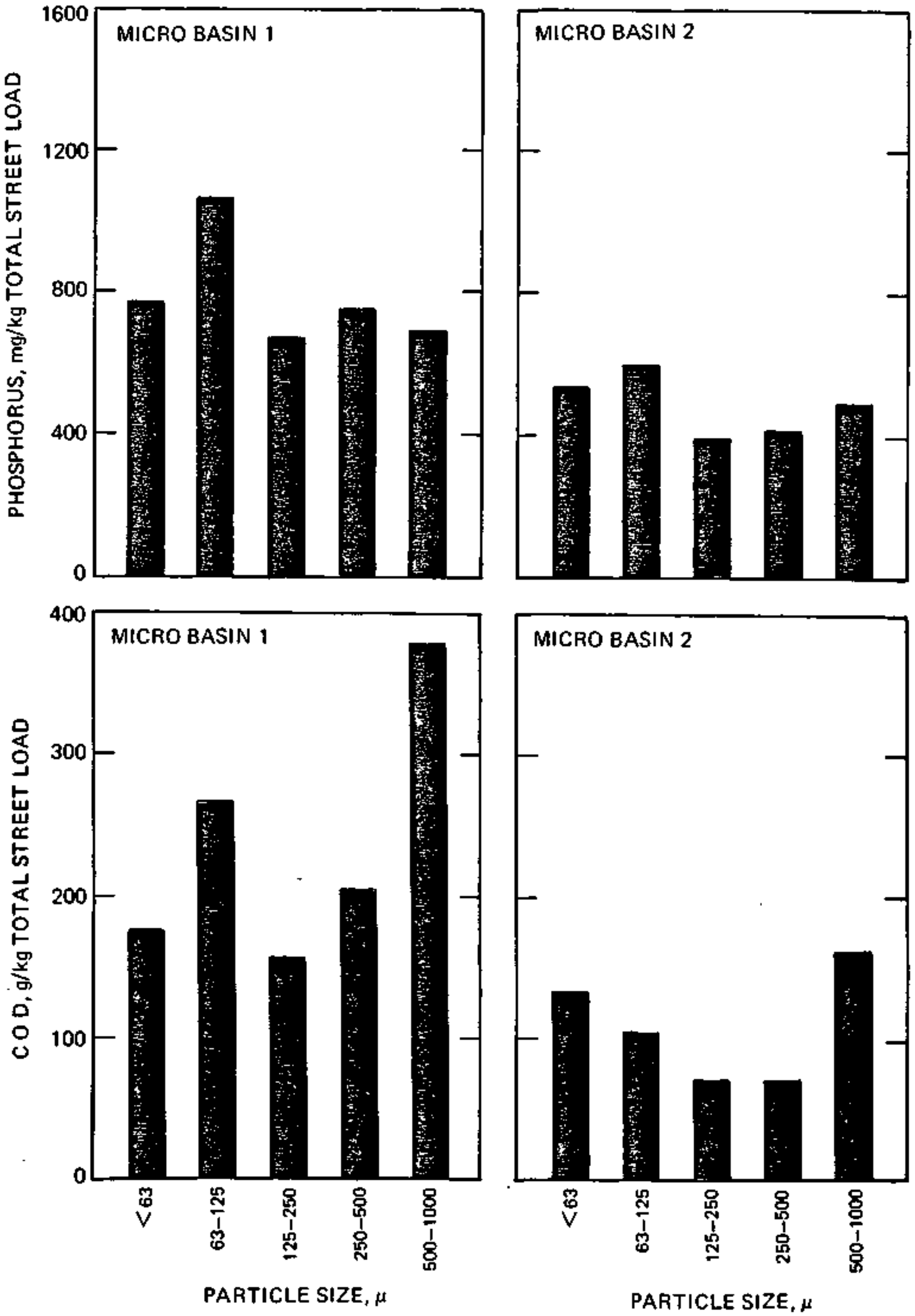

MICRO BASIN 1
MICRO BASIN 2
TOTAL STREET LOAD, g/curb meter
DAYS SINCE LAST CLEANING
100
80
60
40
20
0
0
2
4
6
8
10

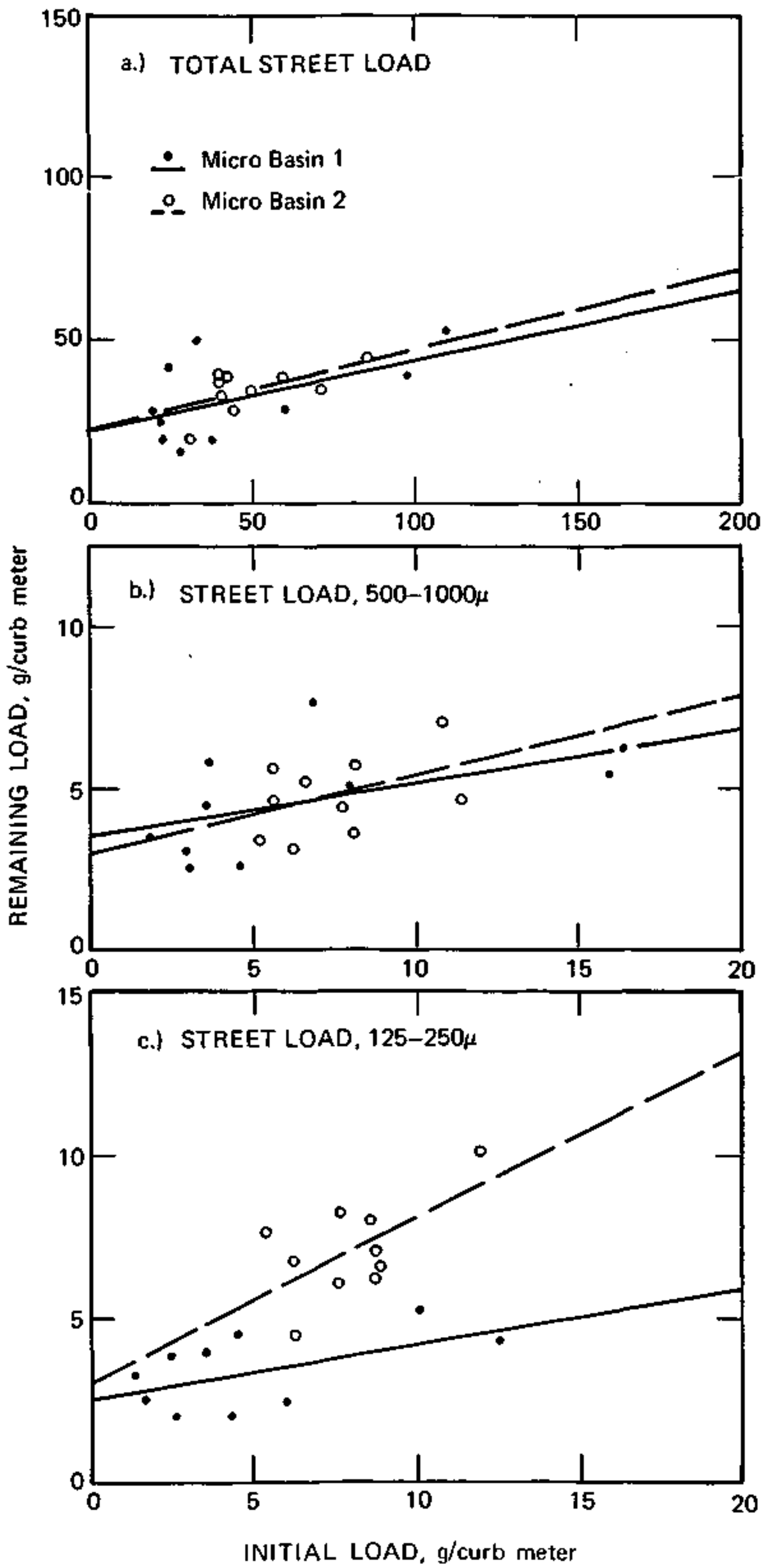

MICRO BASIN 1
MICRO BASIN 2
Range
Mean
PERCENT OF TOTAL LOAD
0
25
50
75
100
<63
63–125
125–250
250–500
500–1000
1000–2000
>2000
PARTICLE SIZE, μ


MICRO BASIN 1
MICRO BASIN 2
LEAD, mg/kg TOTAL STREET LOAD
3200
2400
1600
800
0
IRON, g/kg TOTAL STREET LOAD
80
60
40
20
0
<63
63–125
125–250
250–500
500–1000
PARTICLE SIZE, μ



MICRO BASIN 1
MICRO BASIN 2
AMMONIA-N, mg/kg TOTAL STREET LOAD
400
300
200
100
0
KJELDAHL-N, g/kg TOTAL STREET LOAD
16
12
8
4
0
<63
63–125
125–250
250–500
500–1000
PARTICLE SIZE, μ


PHOSPHORUS, mg/kg TOTAL STREET LOAD
1600
1200
800
400
0
MICRO BASIN 1
MICRO BASIN 2
C O D, g/kg TOTAL STREET LOAD
400
300
200
100
0
MICRO BASIN 1
MICRO BASIN 2
<63
63–125
125–250
250–500
500–1000
PARTICLE SIZE, μ
PARTICLE SIZE, μ



a.) TOTAL STREET LOAD
Micro Basin 1
Micro Basin 2
b.) STREET LOAD, 500–1000μ
c.) STREET LOAD, 125–250μ
REMAINING LOAD, g/curb meter
INITIAL LOAD, g/curb meter